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This is a compilation of papers on a variety of technical and training subjects related to training device technology and training methodology. Representatives include sponsors, users, research, development, and procurement agencies and industry.

The papers in this report were presented at the Eleventh NTEC/Industry Conference held 14 - 16 November 1978. The Conference Theme, "New Horizons for Simulation," was selected to explore the vast new horizons that over →

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simulation will reveal in developing and maintaining readiness of the fleet. The Eleventh Conference is part of a continuing program to promote cooperation between Government and Industry in the development of effective training equipment and foster an exchange of fresh concepts in training technology.

FOREWORD

The Naval Training Equipment Center is pleased to sponsor the Eleventh NAVTRAEQUIPCEN/Industry Conference with the theme, "New Horizons for Simulation."

The major growth of our industry over the past decade can be attributed to inherent economic and ecologic advantages coupled with significant technological advances which have enabled improved fidelity and new applications of simulation technology and training methodology. In particular, it has been through exploitation of modern cost-effective digital computer systems that these achievements have been possible. This same technology will permit the merging of curriculum and equipment into computer-based training systems using the Instructional Systems Development process.

The annual NAVTRAEQUIPCEN/Industry Conference is an important event in continuing the frank and open dialogue that is vital to meeting the challenges of current and future training system development. The constructive and creative environment of this Conference serves as a forum for establishing and maintaining a rapport throughout the training community.

The papers published in these proceedings are from government, industry and universities and they represent all phases of the process from training needs identification to life-cycle logistics support. These proceedings will play an important role in the decision-making process of exploring various concepts and alternatives to satisfy specific training system requirements.

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TABLE OF CONTENTS

TABLE OF CONTENTS (CONT)

TABLE OF CONTENTS (CONT)

INTRODUCTION TO THE CONFERENCE

G. V. Amico
Director of Engineering
Naval Training Equipment Center

The theme of this year's conference, "New Horizons for Simulation," permits us to assess the progress which has been made over the last decade and to forecast the advancement which will be made within the next decade. I would like to briefly cover both the mid- and long-range horizons for simulation technology as it applies to training.

The mid-range horizon will be influenced by the continued advancements being made in the computer field and will center around the development of training systems. These training systems will encompass a wide range of instructional media, primarily computer based or controlled systems, to support major weapon systems. In consonance with this concept, there will be an increase in the use of computer controlled and managed instructional systems. These systems will provide the self-pacing, adaptive and self-evaluating features of the learning process that are geared to the behavioral requirements of the operational systems. Reductions in instructor requirements will be an important feature of these systems.

As the complexity of operational equipment increases through the use of onboard computers with their associated control and display systems, the cost of the operational equipment necessary to support operator and team trainings at multiple sites becomes prohibitive. This cost factor alone will lead to training equipment which can be directly interfaced with the operational system in a matter of hours. The pierside concept for surface ships has already been proved by programs which have been undertaken during the last few years.

The mid-range horizon will also include the development of multi-window, multi-channel computer image generation systems not only for aircraft, but also for surface ships and land based vehicles.

The high cost associated with using operational equipment to support all phases of specialized maintenance training will lead to the use of effective combinations of courseware and simulation hardware for many portions of the curriculum. These maintenance training systems will provide more effective training at a substantially lower cost.

The longer range horizon envisions systems that will be developed in the latter part of the next decade. The direction now being established for the mid-range will continue. The training system approach will have been fully implemented for new weapon systems. These training/instructional centers will employ fully automated curricula under the control of a multi-computer complex capable of monitoring performance against established standards for maintainers, operators and combat teams. These same training concepts will also be applied to operational subsystems with critical and complex training tasks.

The pierside design will move closer to the embedded training system concept. The increased use of computers in operational systems will simplify the connection of the environmental generator and instructor controls to the operational system. This connection may reside within the program of the operational computer or in a satellite computer. Advances in simulation and computer technology will make almost every vehicle serve its own training needs. Through data links, the combat teams in a number of vehicles can be trained to react to various multi-threat scenarios.

High-performance, wide-angle, visual systems using computer-generated imagery will find wide application in many training areas where visual perception is a critical pilot/operator function. Major advancements will be in the areas of display technology.

Specialized maintenance training facilities that integrate the operational equipment maintenance manual/technical data, parts identification and supply functions with the diagnostic/corrective maintenance procedures will rely heavily on simulation technology and computer based integrated courseware.

The major advancements which have been forecast rely heavily on the continuation of current trends in computer development, namely increased capacity/speed at a reduced cost. The Achilles' heel associated with these projections is in the area of software engineering. To date, software engineering problems have plagued every major trainer development. Although the problem is universally recognized, less than satisfactory measures have been taken to remove or alleviate the problem. If this deficiency is not corrected, the bright horizon for training systems will be dark and clouded.

The new horizon for simulation is indeed bright. Its principal feature will be the effective integration of hardware and courseware into training systems. These training systems will encompass a wide range of curriculum and media to satisfy a variety of operator/maintainer training objectives. Both initial and refresher training needs will be accommodated. This conference will permit us to examine that horizon, discuss alternative solutions, and develop an optimum training strategy; a strategy to improve operational readiness as its cornerstone.

ABOUT THE AUTHOR

MR. G. VINCENT AMICO has been Director of Engineering at the Naval Training Equipment Center since 1971. He graduated from New York University with a Bachelor of Aeronautical Engineering in 1941. He was awarded a Masters in Business Administration from Hofstra College in 1954 and a Master of Science in Engineering from Florida Technological University in 1973. Mr. Amico worked on the design of naval aircraft as a stress analyst and project stress engineer with the Curtiss-Wright Corporation from 1941 to 1945. He entered the Armed Forces in 1945 and was assigned to the Static Test Unit of the Structures Laboratory at Wright Field as a structure research engineer. Upon leaving the service in 1947, Mr. Amico joined Republic Aviation Corporation with responsibility for preliminary design of missile and advanced aircraft systems. He joined the Center in the fall of 1948 as a project engineer in the Flight Trainers Branch. Since then he has progressed through the engineering organization, holding positions as Head of the VA-VP OFT Branch; Head of the Aviation Trainers Division; Deputy Director and Chief Engineer of the Special Projects Office and Director of the Sea Warfare Trainers Department. During this time, he was responsible for the development and production of a wide variety of training devices in all warfare areas. Mr. Amico is a member of Tau Beta Pi and Alpha Pi Mu Honorary Engineering Fraternities, American Society of Military Engineers, Society for Experimental Stress Analysis, Research Society of America, Sigma Xi, the American Institute for Aeronautics and Astronautics, and the Armed Forces Communications and Electronics Association. He was past Chairman of the New York section of the Institute of Aerospace Science and the Orange Chapter of the Armed Forces Communications and Electronics Association. Mr. Amico holds two patents and has presented a paper to the Institute of Radio Engineers on Synthetic Training for Space Flight. He coauthored a paper on "The Application of System Dynamics Techniques to the Modeling of the Military Training System" for The Seventh Annual Simulation Symposium.

NAVAL AVIATION INSTRUCTIONAL SYSTEMS DEVELOPMENT

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Growth in the inherent complexity of airborne weapons systems over the last thirty-odd years has been paralleled by the emergence of an equally complex problem - the design of large-scale cost-effective instructional systems. Until recently, the Navy's response to this problem has been much the same as the other armed services and industry. The concept of systems analysis was embraced as an operational strategy and the principles of applied psychology and educational technology were transformed into proceduralized methodologies for training program development. The result was called the Systems Approach to Training (SAT).

The principles underlying SAT were sound, but the approach suffered a fundamental weakness. It lacked a management system capable of directing multiple applications of SAT, i.e., a general control process that would effect a uniform application of SAT across training programs developed for different weapons systems.

By the mid-1970s the Naval Training Equipment Center (NAVTRAEQUIPCEN), acting under the auspices of the Naval Air Systems Command (NAVAIRSYSCOM), had undertaken the task of constructing a generally applicable model for Instructional Systems Development (ISD). The ISD process was divided into five major phases of activity: analysis, design, development, implementation, and quality control. The activities to be carried out within each major phase were identified and further developed into logically coherent procedures that made explicit the key decision points, specific objectives, and end products required at each stage in the process. The resulting standardization of the ISD process made possible effective management control throughout the successive stages of each developmental project, and it permitted cross-project comparisons essential to further refinement and generalization of the process.

The NAVAIRSYSCOM/NAVTRAEQUIPCEN model of the ISD process has been widely applied in the development of a variety of training programs throughout Naval Aviation, and the model has undergone several revisions in response to feedback from these applications. As a management tool, the model has proven its value, but it continues to be evaluated as experience accumulates. The present formulation of the model is described nontechnically in the paragraphs that follow.

Whether the model is applied to a newly emerging weapons system, or to an existing system, the ISD process always begins with a problem analysis. Generally, the ISD process is initiated by a documented indication of a need for a new training program or a revision of an existing system. This initial documentation identifies the nature, scope, and criticality of the training project. If it is found to be of sufficient magnitude to warrant further consideration, an in-depth problem analysis is planned by the NAVTRAEQUIPCEN. After the plan has received the approval of the NAVAIRSYSCOM, and the lines of communication have been established among the various participating Navy organizations, a full-scale problem analysis is launched under the direction of the NAVTRAEQUIPCEN.

The primary objective of the problem analysis is to establish the precise nature of the training effort that will be required to achieve an effective instructional program. In the case of an existing training program, every aspect of the system is examined and evaluated in order to identify the needed revisions and the appropriate strategies for making them. The analysis would include everything from instructional syllabi, training materials and devices, tests and student attitudes to management efficiency and instructional goals of the existing system.

In the case of an emerging weapons system, the analysis is directed toward a preliminary determination of the tasks required to operate the system, the kind of training program, materials, and devices that will optimize student learning of the required tasks, and the structure of the Navy organization that will be needed to develop, implement, and manage the instructional system. In the case of either an existing or an emerging system, the problem analysis identifies the personnel, facilities, equipment, time, and costs required for development and implementation of the needed training program. This information is evaluated relative to program goals and assets, and a Problem Analysis Report (PAR) is prepared. If the projected

goals and requirements of the needed training program, as documented in the PAR, are approved by the NAVAIRSYSCOM, the development of a program master plan is initiated.

The program master plan (PMP) serves as a tool for managing and coordinating the ISD project, and it incorporates the information contained in the previous problem analysis together with other information such as the latest funding analyses available and costs data from previous ISD projects. The model is also taken into account in the PMP since the model delineates the stage-by-stage progression of ISD and stipulates the products generated at each stage. All this information is integrated by the NAVTRAEQUIPCEN and the PMP is formulated.

The plan states the objectives of the proposed ISD program, and the procedures by means of which those objectives can be realized. The major milestones of the ISD project are specified, and a method is provided for tracking the various stages of the development process. The resources and facilities required for the ISD project are inventoried together with the sources committed to making them available. The plan also stipulates the organizational roles and responsibilities of participating organizations and personnel, and provides a system for their coordination. The plan even designates the specific jobs to be performed throughout the ISD project, and indicates when each job is to be performed, and by whom. The plan also identifies potential funding sources, gives cost estimates for each of the successive stages of the ISD project, offers various procurement strategy options, and describes the materials needed to carry out appropriate procurement procedures. Thus, the PMP serves as the primary management tool for directing the development of a large-scale instructional system. If the PMP is approved by the NAVAIRSYSCOM, the project may then move ahead into the more detailed task analysis stage where the real job of behavioral specification and instructional design begins.

It is in the analysis phase of ISD where the techniques of modern psychology and instructional technology are applied most intensively in the model. The analysis phase begins with the question, "What are the tasks that must be performed in order to operate the system in question, and under what conditions must these tasks be performed?" The answer to this question is obtained through a <u>task analysis</u> of the operational system.

First, system operation is partitioned into the major job responsibilities required for each mission phase. Then, each responsibility area is further analyzed to identify the primary task components that must be performed. Each task component is described in a detailed and standardized fashion. A task description states precisely the conditions under which the task is performed, the actions that compose the performance, and the particular outcomes of the performance. This emphasis on task identification and description is based on the psychological principle that "the more accurately a behavior can be specified, the more efficiently it may be trained." Thus, task analysis generates task specifications, i.e., descriptive statements of the conditions, actions, and outcomes that compose each task component. By organizing these task descriptions according to responsibility areas and mission phases, an accurate picture required to perform a job is obtained.

The task analysis and listing process is usually carried out by a team of subject matter experts (SMEs), Navy personnel experienced in the operation of the weapons system under consideration, who have been trained in ISD methodology by a behavioral specialist. Together, the specialist and SMEs form the <u>ISD team</u> responsible for producing the <u>initial task</u> listing. To ensure that the task descriptions are accurate, and that the task listing is complete and properly organized, an independent group of experienced fleet personnel evaluates the work of the original ISD team. They also estimate the frequency and criticality of performance of the individual tasks. This step in the ISD process is referred to as <u>task validation</u>, and it may result in a revision of the original listing. As a means of standardizing the validation procedure, the ISD team prepares a questionnaire which is used by fleet personnel to evaluate the task listing.

Now that the tasks have been behaviorally specified and functionally organized, the validated task listing is subjected to another kind of evaluation. Each task in the listing is examined systematically by the ISD team in order to determine the level of training that it will require.

Depending on the entry-level skills of the new Fleet Readiness Squadron (FRS) trainees, as compared with the standards of acceptable performance for individual tasks, the ISD team will assign each task to one of five different training categories. These five categories are; full-scale, review-only, familiarization-only, deferred, and no-training required. For example, if a given task has to be performed frequently, and if its performance standard exceeds the entry-level skills of trainees, the task would be scheduled for full-scale FRS training, especially if correct performance on the task were critical. On the other hand, even a high-frequency task might be classified as requiring no training if its performance were already well within entry-level skills of new trainees.

As a result of this careful procedure of task selection, a major benefit is achieved. Resources and time are not wasted on unnecessary training, and tasks that are essential to competent performance are not overlooked in the training program. Rather, the approach taken is to assign each task to just that level of training which is necessary to assure that its performance will at least meet the operational standard.

At this point the tasks selected for FRS training are reviewed to determine which of them must be trained in either real, or simulated, operational environments. Tasks that require live enactment or perceptual-motor skills involving realistic visual, auditory, motion, etc., cues are designated for "hands-on" media training. This group of tasks is further divided into two categories; those that must be trained only in actual flight conditions (or only on actual operational equipment), and those that can be trained under synthetic operational conditions. It is the latter group of "hands-on" tasks that are of interest at this stage of the ISD process.

Analysis of the conditions and standards associated with these tasks enables the ISD team to arrive at a definition of the kinds of training devices that will be needed for simulated "hands-on" training. The attempt here is not only to select the most suitable training medium for each task, but to identify as early as possible those media which require long lead time for design and production. This permits parallel development of both the training program and the synthetic training media, thus avoiding costly delays in implementation.

The armed services have long recognized that training devices are less expensive to use as training media than actual operational systems. The savings in personnel time and fuel consumption alone are sufficient to warrant their use in training programs. But it has also been recognized that synthetic devices enable the training of many procedures (such as those involving emergencies) that could not otherwise receive any degree of instructional attention. However, the approach taken by the model extends the advantages of training devices even beyond this level of utility.

In the model, behavioral objectives of the instructional program control training device specification. This concept is in marked contrast with the old notion that a training device should simulate the operational system as closely as possible. To the surprise of many, a training device optimally designed to meet behavioral objectives may involve considerably less simulation than those produced by the traditional approach to training. Furthermore, where device specifications are governed by behavioral objectives, the devices are not only more effective as training media, but they may be less expensive to produce and operate. Since just that degree of simulation that is necessary to adequately train tasks is incorporated into a device, the expense of unnecessary simulation is avoided. Training devices designed to the specifications generated from the ISD approach are thus effective for minimal cost. It is significant that these devices are designed to be an integral part of the overall training program to serve as instructional media with specific training objectives. This assures an extensive utilization of available devices and, consequently, the realization of a higher return on the Navy's investment.

What we have seen up to this point in the ISD process is a systematic analysis of the behavior necessary to operate a weapons system. For each operator position, the necessary behavior is broken down into its component tasks, and these tasks are organized into the functional units that occur within each phase of a mission. The task listing is independently validated, and, if necessary, then revised. The conditions, outcome, frequency, standards, and criticality of performance of each task is specified. These factors, together with an assessment of entry-level skills of new trainees, provides the data needed to select the tasks to receive FRS training and to designate the type and level of training required for each task. "Hands-on" tasks that can be best trained in synthetic devices are identified, and this enables an early specification of the training devices that will become an integral part of the training program.

While the analyses of behavior carried out thus far are adequate for task specification and selection, an even finer analysis is necessary to determine the nature of the behavioral objectives that the training program must be designed to achieve.

The distinction between tasks and behavioral objectives is fundamental to the ISD methodology, for it is the objectives that control the detailed aspects of instructional design. It may be said that, whereas tasks are what a person must do to operate a system, behavioral objectives are what a training program must achieve to produce competent task performance.

The behavior required to perform a complex task always contains a number of component skills, concepts, decision-making strategies, etc. Consequently, whole-task performance cannot be trained satisfactorily until its more basic components have been learned. For example, the use of an on-board computer to calculate the time-of-arrival at some distant destination requires that the operator not

only possess the fundamental computer skills, but he must also have knowledge of the more general navigational principles and techniques, as well as the basic mathematical skills essential for numerical computation. Use of the on-board computer and applications of navigational principles could not be taught effectively if the trainee did not first possess the elemental mathematical and computational skills.

So by breaking down a task into its fundamental components, and by comparing these with the skills already present in the behavior of the new trainees, it is possible to identify the particular behavioral components of a task that must be individually trained. These task components become the behavioral objectives to be achieved by the training program.

This analysis of the behavior required to perform a task, however, only yields a set of target behaviors that the ISD program must be designed to produce in trainees at criterion proficiency levels under specified conditions. These target behaviors, or terminal objectives, may be many steps removed from the basic entry-level skills of the trainees. Thus, the behavioral components intermediate between entry-level skills and terminal objectives also must be enumerated.

Again, the driving principle behind this progressively more detailed analysis of behavior is to make explicit that which must be trained. Intermediate behaviors are prerequisites for task performance. The relationships among intermediate behaviors and target behaviors form an organizational hierarchy shaped like a pyramid with the behavioral objectives located at the top. Behaviors listed at each level of the objectives hierarchy are always prerequisite and essential to performance of the behaviors listed at higher levels in the hierarchy.

Construction of objective hierarchies is a crucial step in the ISD process for several reasons. First, the construction procedure helps to ensure that the ISD team will not overlook any important intermediate behaviors. Second, the hierarchical organization of the intermediate behaviors leading to each behavioral objective shows the sequential order in which these behaviors should be learned. And, third, the entire subject matter content of the instructional program is delineated in the hierarchical organization of the behavioral objectives. Thus, objective hierarchies provide a complete picture of the diversity of behaviors, and their interrelationships, that must be encompassed by the instructional system.

Now that the question of what to teach has been definitely answered, the next question to be addressed is how to teach it most effectively? An answer to this question must be obtained for each behavioral objective, and each answer must identify both the method and medium for instruction that will optimize student learning of the behavior.

Knowing what to teach is usually not synonymous with knowing how best to teach it. For this reason, the model provides the ISD team with a decision-making procedure which can be used in a straightforward manner to select methods and media given certain inputs to the process. The ISD team first determines the resources that will be available for instruction, i.e., the funds, personnel, and facilities. These resources set limits on the range of methods and media from which the team may select. After this is established, the ISD team looks at the subject matter content of each behavioral objective to ascertain the kind and level of learning involved, the level of competency students will be expected to obtain, the kinds of interactions with instructors and materials that will be needed to substantiate and motivate learning, the specificity and source of response-contingent feedback necessary for self-corrective learning, and the characteristics of information displays essential for effective presentation of the subject matter. When this information has been obtained, the ISD team is ready to begin the decision-making process that will result in the optimal choices of an available method and medium for each particular subject matter under consideration.

Advances in the application of electronics to the development of instructional media has had a profound influence on educational technology. This is especially evident in some of the applications of computer science. Consider, for example, the sophisticated visual and auditory displays now utilized in modern instructional media and simulation devices, the advanced computer programs that allow for student interaction and provide response-contingent feedback, and the many kinds of information processing systems that extend the limits on man's memory and thinking capabilities.

No longer must the quality of instruction be invested primarily in the expertise, ability to communicate, and motivating influence of the traditional instructor. The diversity of methods and media existing today permit the instructional designer to choose the one that is most appropriate for each behavior to be trained. Furthermore, the new methods and media rely less on the instructor operating as a lecturer, motivator, and evaluator. In ISD programs, instructional presentation and evaluation is individualized, and motivation is maintained through reinforcing contingencies built into the progression of events each student encounters as he moves through the

program. This shifts the responsibilities of instructors and students from those of lecturer and pupil to those of guide and learner. The respective role of each is enhanced, as is their motivation to perform well. The new responsibilities of instructors and students in the training program are largely due to the methods and media selected for use, but they are also dependent upon the way instructional courses are developed and sequenced.

The sequence of instructional experiences through which the students move in an ISD training program is stipulated in a course syllabus, a kind of map in which behavioral objectives are organized into lesson sequences. A given course is divided into major units of instruction, and each unit consists of a number of lessons which are further broken down into individual segments. These divisions of a course are sequenced to lead onto each other such that the student is moved in a steady path from lower to higher order knowledges and skills.

The progression of learning experiences is arranged so that the student's knowledge and skills build in increments small enough to never overextend the students' capability, but large enough to ensure an optimal rate of progression from entry-levels to the more complex job-levels of performance. This kind of arrangement is designed to prevent failure at one point in a course due to incomplete experience gained at previous points in the course. At each stage, the student has all the experience he needs to proceed successfully to the next stage.

Instruction programmed in this fashion has proved to be a far more efficient approach than the traditional one because it not only reduces failure to a minimum, but it also produces a high level of student motivation. When effort-to-learn results in success, this feedback motivates the student to continue. Thus, the sequential ordering of learning experiences into well-designed course syllabi is a crucial aspect of the ISD process. It is at the stage of syllabi development that the ISD team moves from behavioral analysis to instructional design, incorporating the information contained in the objective hierarchies into a framework designed to maximize learning.

The transformation from objective hierarchies to course syllabi is nearly as complicated as it is important, and ISD team members require some training and expert guidance in this process. Essentially, the question they must answer is "into what sequences must the behavioral objectives be ordered?," and this question must be answered for each behavioral objective.

Usually, the position of a behavioral objective in its hierarchy will determine its sequential position in a course syllabus. Objectives located at the bottom of a hierarchy are more elementary than those above it and, thus, should be taught first. However, if all low-level objectives were taught before moving up the hierarchy, the student would tend to become bored and possibly even forget some of the information he has already learned because he would not have had an opportunity to apply it. So, this problem is avoided by introducing "hands-on" experience into the syllabus as soon as possible. Generally, this can be accomplished by limiting successive sets of objectives to vertical legs of the hierarchy. In other words, the designer starts with the lowest objective on one vertical leg and moves up to the point where a "hands-on" objective is encountered. The latter may be anything from a familiarization exercise in a trainer to an actual flight in an aircraft. This type of sequence cycles the student from purely ground school type situations to equipment exercises, then back to ground school for more basics followed by further equipment exercises.

This type of cycling maintains the integrity of the objectives hierarchy while allowing the student to practice his newly acquired skills as soon as possible. In this way, a small portion of the syllabus is encountered, learned, and practiced before the student moves on. Those objectives requiring actual flight in the aircraft are preceded by objectives of a more elemental nature that are practiced in a trainer or simulator. The objectives prerequisite to trainer exercises are still more elemental, and they constitute the content core of ground school instruction. Typically, the student would go through several evolutions of the cycle between ground school and trainer exercises before cycling up to an aircraft flight, and the objectives to be accomplished in the first aircraft flight would be less difficult than those scheduled for later flights. At each stage in the syllabus, the student is prepared to advance to the next stage.

Segment-by-segment, the ISD team organizes related behavioral objectives into lessons. Elemental lessons are placed ahead of more difficult ones in the syllabus, and a test is scheduled for each lesson. The lessons that pertain to a given subject matter are organized into instructional units, and an equipment exercise is scheduled at the end of each unit. Finally, the various units of instruction are structured into a framework that forms the course syllabus.

Not only do course syllabi serve as maps of the instructional sequences for the entire training program, but also they provide the

ISD team with a sufficiently complete picture of the program to permit an accurate analysis of the new program's training support requirements. Consequently, it is at this stage that the ISD team estimates the total personnel, equipment, services, materials, and facilities that will be required to complete the development of the training program, and to implement and maintain it throughout its life cycle.

For example, the trainer specifications generated earlier during task selection are now reexamined to determine if each trainer will encompass a sufficient number of objectives to be utilized fully, and if each is the least expensive device that can be effective in training the specified objectives. Similarly, the classroom media selected earlier are now evaluated to determine which media are most feasible for presenting the information within each lesson. The answers to these questions enable the ISD team to estimate the purchase, modification, production, and operating costs required for the various trainers and instructional media. However, in order to estimate personnel, services, and facilities requirements, the ISD team must construct a daily time-based class schedule for all courses in the training program. From this, the team can establish the student flow throughout the program and the support requirements on a lesson-by-lesson basis.

Training support requirements analysis provides the information needed by planners and managers to assure the availability of critical support resources needed for satisfactory completion of the training program and its ultimate implementation and maintenance. By basing this analysis on completed course syllabi, a major source of potential program failure is avoided, i.e., failure due to the unavailability of some key instructional resource around which much of the training program implementation is dependent. Rigorous support requirements planning at this stage in the ISD process ensures that only those resources available to the program are incorporated into its design.

Now that the skeleton of the program has been built and the resources needed to support it have been established, the time has come for the ISD team to put some meat on the bones, i.e., to write the lesson specifications. The critical subject content and teaching strategy must now be specified for each behavioral objective in the course syllabus. For example, if in order to achieve a particular objective, the student must learn a rule, a definition, a fact, or a procedure, the ISD team must state it explicitly. Likewise, if a particular kind of explanation, or mnemonic aid, will facilitate learning of the objective, this also is specified. In addition, the ISD team determines the various kinds of illustrative examples, practice problems, and test items that will best exemplify and evaluate the behavior called for in the objectives. The team also stipulates the graphic illustrations to be included in the instructional material for each objective. After this has been completed for all the objectives covered in a given lesson, a lesson format guide is prepared which explains how the material in each segment will be organized, and how the individual segments will be tied together to form the lesson. The output from this stage of the ISD process is a set of tight guidelines that will be used to control the organization of the detailed subject matter content.

The guidelines help to avoid the kind of instruction which gives either too much, or too little attention to certain materials, misses the point, or buries it in a mass of detail, or ignores fundamental considerations of teaching strategy. Proper lesson specification ensures that the principles to be learned in any group of behavioral objectives determine both the kind and degree of detail given, as well as the strategy that is chosen to teach it.

The lesson specifications and format guides provide the ground-work for actual lesson authoring. Working from the specifications of lesson contents and format, the ISD team writes out paper and pencil versions of the final instructional materials. After review and editing, these materials go into prototype production for use in small-scale tryouts with real students. Usually, these prototype instructional materials are scheduled for tryouts as they are being developed. By means of these tryouts, the ISD team is able to determine whether the materials are actually effective in bringing about the desired learning, and to establish whether the materials are palatable to the students. Instructional materials that are found to be weak in either respect are revised and, if necessary, tried out again.

This procedure maximizes the probability that the instructional materials will be successful once the training program is implemented. After the materials have undergone their final production, the finished product is a package that comes as close to guaranteeing effective instruction as can be provided by modern technology. However, in order for this training package to remain effective throughout its life cycle, it will not only have to be managed properly, but it will need to be amenable to continuous evaluation and updating.

Once the instructional media and materials have entered the final production phase, the ISD team can turn its attention to developing a plan that will control implementation,

operation, and long-term evaluation of the training program. It is at this point that the basic instructional management system is established. This system defines the role of instructional personnel, the student management procedures, and the procedures for resource allocation and scheduling.

Built into the management process is a quality control system designed to continuously assess the effectiveness and palatability of the instructional materials, as well as the instructional management system itself. The objective of this quality control system is to provide a mechanism for identifying those pieces of instruction that require modification, and for assuring that the needed modifications will be made in a timely and smooth manner.

This is the final task of the ISD team. Upon its completion, the team will have developed, designed, and produced a superior instructional system, one which can be implemented and managed efficiently for the lifetime of the program. The built-in quality control system assures that the program will always accomplish what it was designed to do and that its materials will be revised to reflect the changes in conditions and constraints that will probably lie in the future. Such a program should be as fresh and effective at the end of its life cycle as it was at the beginning.

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TRAINING ANALYSIS FROM AN OPERATOR'S POINT OF VIEW

LARRY H. NOWELL
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It is difficult to single out a group of people and say that their job performance affects the combat readiness of the fleet without mentioning the Operations Specialists in Combat Information Center (CIC). The operators collect, translate, display, evaluate, disseminate data and make recommendations in relation to Anti-air Warfare Surface Warfare, Subsurface Warfare, Electronic Warfare, gunfire support, ship maneuvers, data-link operations and communications. I am not trying to say that they alone do all of these tasks, but it is normally their input that affects the total outcome. The Tactical Action Office (TAO) cannot do their job unless targets are detected and displayed. Surface and Subsurface Warfare would wind up in knuckles (disturbance in the water caused by ships making tight turns that can be mistaken for submarines) without maneuvering boards and NC-2 plotters. The Air Intercept Controllers (AIC) and Antisubmarine Air Controllers (ASAC) are the data and voice links to all aircraft. Many Officers of the Deck (OODs) have been saved from a near miss or going aground by alert operators in CIC.

I am proud of the fact that I was an operator for 20 years in the Navy. The first school I attended in the Navy seemed to set a pattern for things to come. I spent more than two years attending schools and eight years teaching operator training. At least half of my Naval career was spent in schools. I have felt the enlightenment of learning, the satisfaction of teaching, and the frustration of failure. Failure to teach someone a skill you know he is capable of learning can be very frustrating.

I experienced many benefits as a result of the time I spent in school. In 1972 I was awarded the Distinguished Service Medal. I am the only enlisted man to ever receive this nation's third highest award for combat action.

After receiving so much from Navy schools, I feel I am extremely lucky to be able to continue working on training systems in the civilian community.

In this paper I have tried to describe some problems in the training of operators, the reasons why I feel they have occurred, and my recommended solution. The main problems in operator training (as I see them) are the following:

a. training time is limited
b. present teaching methods are out of date
c. little standardization in NTDS programs
d. shortage of qualified instructors aboard ship
e. reduction in training time for qualification of new personnel reporting aboard ship
f. high cost and increasing number of operational consoles.

Training in the Navy is a way of life. The Navy and Naval personnel are very proud of their schools. The Navy schools are one of the reasons I decided to join the Navy. The schools I attended allowed me to perform my job and take pride in my performance. Being able to obtain job satisfaction was a motivating factor to stay in the service.

Rate training is taught primarily in schools. The formal training being performed concentrates on teaching basic knowledge that cannot be picked up easily aboard ship. The instructors assigned to the schools are recommended for instructor training by their previous commands before being assigned to teach at a service school. Each instructor attends an Instructor Training School to develop the needed skills of presenting material to the students. Much effort is expended in preparing sailors for instructor duty. The primary restricting factor to the school is time. Time spent at school is time away from the ship.

Time was not always a problem. Training on the job was always the primary teaching site. Each petty officer is expected to conduct on-the-job training. A portion of each watch is spent in training. The best way to pass a mid-watch was to have a well-planned training exercise. The bridge would always welcome training during slow watches. Ships steaming in company would join in the training exercises. Predeployment training plans determine where the main thrust of the training would be placed during a deployment. New operators are properly introduced to the job they are expected to do in a one-on-one (instructor-to-student) environment. An operator spends many hours under close supervision before he is allowed to operate on his own.

For a long time I felt we had a good balance in training. The schools were teaching the needed information, and everyone

aboard ship was doing his part to ensure good performance by the operators.

As a result of the reduced size of the fleet, an acute shortage of experienced personnel aboard ship and the time to train new men reporting on board forced the fleet to require better trained personnel. The mark was set at requiring (with a minimum indoctrination period) the graduates to be condition III qualified.

Condition III is wartime steaming. To expect a graduate to step aboard ship and, after a couple of watches, be qualified to "fight the ship" leaves everyone with a problem. I feel the fleet is willing to give the schools some additional time for training, but not a great deal.

The Naval Tactical Data System (NTDS) has to receive at least some of the credit for the training problems. Only three ships carried NTDS for a long time. Most reports from the NTDS ships were good. Everyone wanted to get aboard one, but only a few were allowed. To correct some initial problems and keep the NTDS programs running, changes were being made faster than the school could keep up with, resulting in the output of outdated information. As we were about to get everything together, a new display console hit the street. Most people liked the new console better. The school now had a problem. The school was teaching the equipment. This knob does this when you throw it, see. The school even threw in some information about the computers but somehow never got around to teaching the operators their job. It could have been the way operator training has always been taught, or that the instructors (most instructors had never been aboard an NTDS ship) did not know the jobs. Primarily, the schools started teaching the new consoles and the differences between the consoles. Other events occurred to add to the problem such as:

a. The programmer responsibility was changed from Navy officers to civilians, creating a new learning period for the civilians.

b. Four consoles are being used in the fleet today and more are being developed. To operate a piece of equipment effectively, personnel must become intimately involved with the controls. Since the equipment becomes a part of the operator (an extension of his need for information), he must be able to extract the needed information without looking at the controls or breaking his line of concentration. Each new console has rearranged the operator controls, which means more time and money spent in retraining.

c. Two different program centers are writing programs with little standardization. Four major program developments have occurred, each with some modification, with each program changing the operator controls. For an example, on the east coast the operators are taught the Utility Mode which expands the operator's capability to perform needed functions. All of the smaller ships on both the east coast and west coast have the Utility Model. The west coast teaches Split Labels which does basically the same thing, but there is no changing of modes. All the large ships, east and west coast, use them. It has been planned to teach all operators on one coast. Wonder which program they will teach? There is an estimated requirement to teach 3,000 students a year. Starting a class each week which lasts for 3 weeks (very minimum training time) means that we have to contend with 60 students per class x 3 weeks = 180 students in training every day. Each student needs a minimum of 4 hours on a console each day, which equals 720 equipment hours. Allowing for 16 hours a day, 45 consoles are needed, up and running all the time, every day.

To teach the proper program, we could split the class into those going to the east coast and those going to the west coast. Then, divide each of these groups into four or five units to allow for console differences. We need 8 to 10 mockups totally dedicated for operator training. Each mockup would require at least 6 or 8 consoles to allow for a difference in student load. A total of 80 consoles would be required allowing for downtime and growth. My estimate, based on a recent study, indicates that the cost of using shipboard equipment to train operators is approximately $1 million per station, or $80 million. Of course the cost may go down a bit if purchases are made in quantity.

I have confidence in the Naval school system, and since the two programming centers have shown signs of coordinating their efforts our next program development effort should be one of the best. Instructional System Development (ISD) and the systems approach to training are the best things to come along to help operator training. As ISD is incorporated into the schools and the instructors become more familiar with it, I feel our teaching methods will work themselves out.

Given that this is true and the instructors have improved their teaching techniques, the remaining problem is the number of consoles in use in the fleet. One solution

might be to pack the schools with all types of consoles found in the fleet and teach the trainee on the one he has aboard his ship. Even if money and space were available, this shotgun technique is bound to fail. It is now time to analyze the problem in a logical manner.

We need a training program to bring the student up to a defined level of proficiency. To do this we need to measure the student's ability to perform required tasks. We need a program that is objective and adaptive to the student's needs.

The use of operational programs seriously limits the teaching capabilities of any training system. The basic requirements needed to teach the operators their performance skills have not changed; they are still the same as when NTDS was first introduced. Some additional requirements have been added, but the basic needs of the system that require manual input and modification have not changed. The basic requirements for the operator to perform his task are needed — nothing else. Teaching operator techniques establishes a need for the operator to obtain information from the console or to give inputs to the system. These basic tasks have not changed and could be any or all of the following:

a. entering new tracks
b. tracking targets
c. obtaining bearing and range to a target.

A handful of tasks would allow most operators to perform their job in a condition III environment. There is no NTDS equipment anywhere dedicated to individual NTDS operator training. That bears repeating! There is no NTDS equipment anywhere dedicated to individual NTDS operator training!! Even if four mockups were available with four different types of equipment, the training center schools would be fighting for their use. The NTDS operator schools are lucky to get one mockup for training.

To divert the soaring cost of shipboard equipment and to obtain a usable training console that would allow for a learning environment, I propose an adaptive training console. An adaptive training console would not only adapt to the needs of the student but also to hardware and software changes at a minimum cost. A console designed just for teaching! Let's take a look at it. First, a student/training system interface is needed. An off-the-shelf CRT and keyboard will do nicely. Introductory information, student sign-on/off, new material, some teaching and testing of knowledge subjects, review of past performance, and student status will be conducted.

Using a preparatory station is very cost-effective. While the primary station is being used by a prepared student, a smaller, cheaper station is preparing the next student. The primary training station will also have an interface, CRT, keyboard, and the Adaptive Training Console (ATC). The ATC presents and configures itself according to the level of the student.

After identifying the basic jobs of the operator, the training system presents the job and the need for information from the console or a need to input data. To this point the console is blank. No knobs, switches, alerts, controls, or alarms (see Figure 1). As the need for a switch, knob, alert, control, or alarm arises, it will be presented by the training system (see Figure 2).

As the student's knowledge and skill builds, so does the console. This training system is designed to give prompts to the student when needed. It is easily adapted to other equipment design for training, data readouts, and IFF control boxes. A line printer will be furnished for hard copy printouts.

After the basic skills are learned, the console adapts to the required operational console. The ATC adapts to the individual needs of the student by presenting the likeness of the console aboard his ship to the student. Each ATC has the capability to duplicate the functions of each console being used in the fleet (see Figure 3).

The adaptive training console can be reprogrammed by the training center to adapt to hardware and software changes as long as the basic functions do not change. A change in operator functions would require minor software modification.

The adaptive training console will give the schools a base from which to establish the most effective operator training available. The adaptive training console may very well be the last console the school will buy!!

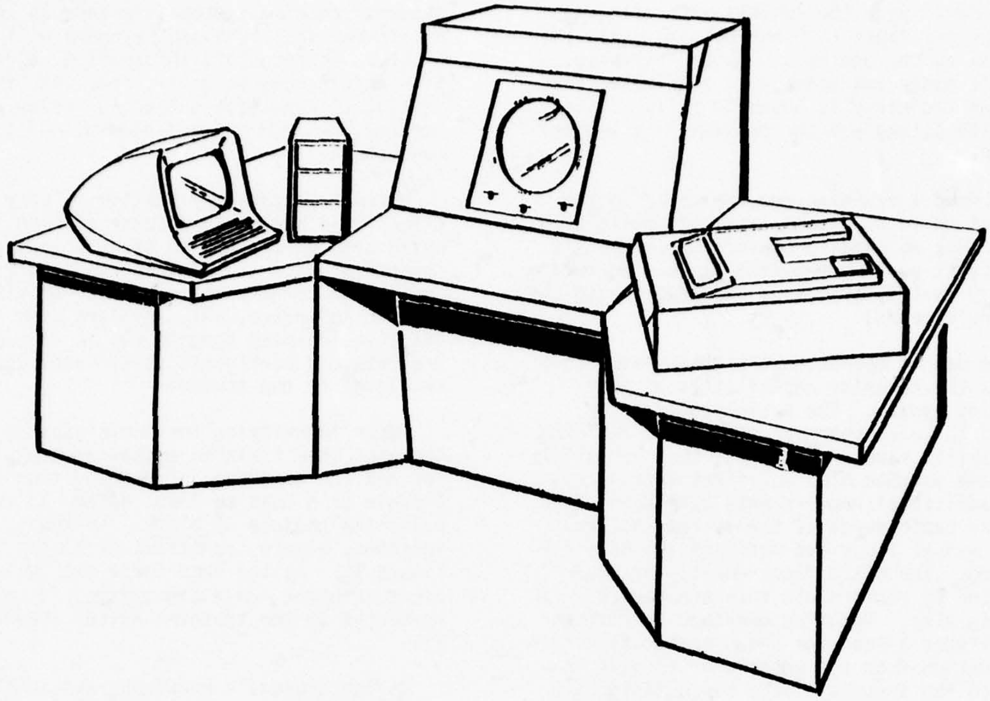

Figure 1. ATC Prior to Learning
(All controls are blank prior to the need.)

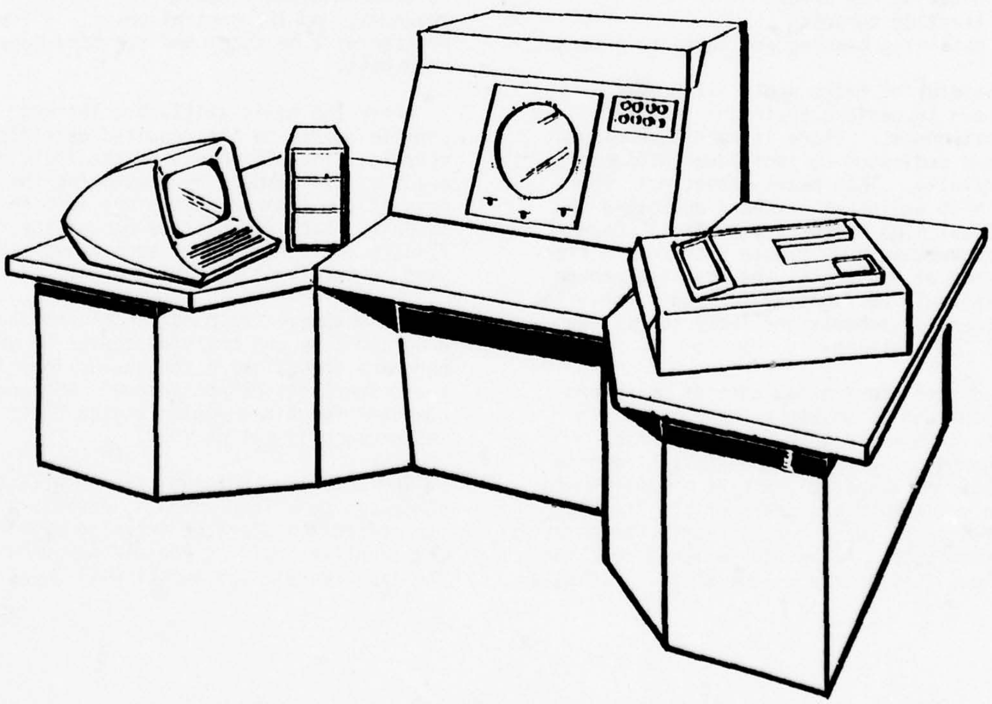

Figure 2. ATC Adapts to Student Needs
(As the need for controls is taught, the controls are presented.)

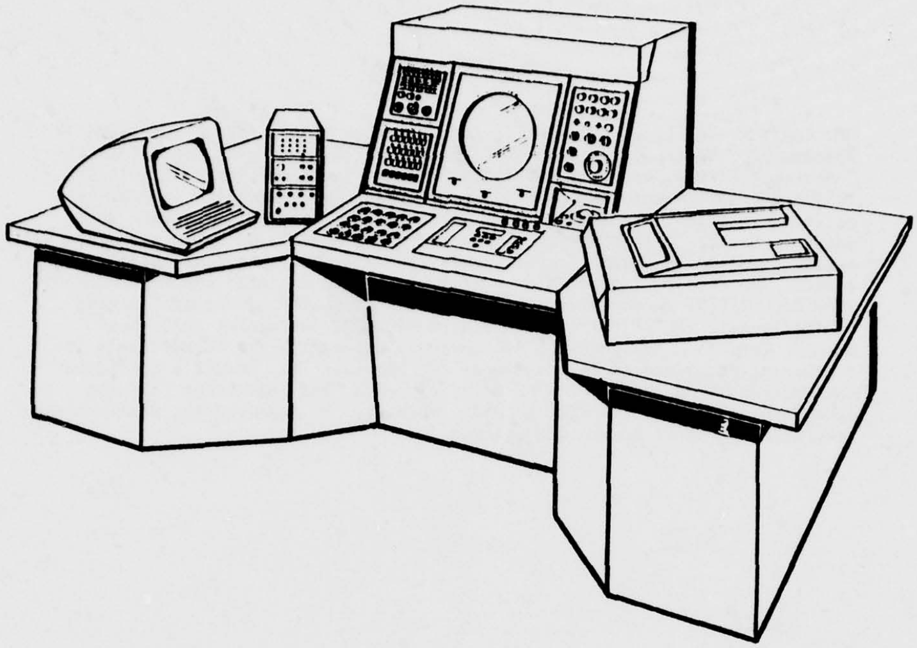

Figure 3. ATC Duplicates Student's Shipboard Equipment

ABOUT THE AUTHOR

MR. LARRY H. NOWELL is a member of the technical staff, Advanced Systems Department. He is writing the syllabus for the Ground Controller Approach-Computer Training System (GCA-CTS) and the Air Intercept Controller (AIC) Laboratory System which incorporate self-paced, individualized, computer-assisted instruction and automated speech recognition and generation technology. He was on-site project coordinator for the design of an instructional system for teaching Naval Tactical Data System (NTDS) operators basic input skills. He also participated in a study for Naval Training Equipment Center (NAVTRAEQUIPCEN) which reviewed AIC training at the Fleet Combat Training Center/Pacific (FCTCP). He was a Senior AIC/AICS instructor there and rewrote the basic AIC and NTDS AIC courses, designated the requirements for a trainer, and aided in the design of its housing. Mr. Nowell's education includes Radar "A" and "B", NTDS User, AIC/AICS, and Instructor Training schools plus digital computer program training. He received the Distinguished Service Medal while on the USS Chicago.

USER ACCEPTANCE IN AN AUTOMATED SPEECH TECHNOLOGY BASED TRAINING SYSTEM

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INTRODUCTION

Computers are no longer deaf and dumb! The automated speech technologies (AST) have made it possible for computers to converse with their users. Now computers can actually understand the spoken word and can speak as easily as they can print. In theory, simulation of the verbal behavior of persons in the environment is now possible. In practice, the current state of the art imposes some rather severe limitations on such simulations. This paper describes some practical problems encountered in the development of a speech technology based training system for use in an environment where user acceptance is of paramount importance. The design solutions to these problems suggest that the state of the art has advanced to the point where speech technologies can be integrated successfully into today's operational simulators, albeit with care in demanding environments.

Background. Logicon's Advanced Systems Department has long been concerned with the automation of training. Since 1969, we have been studying the application of the automated speech technologies to the training environment. In 1974 we delivered a laboratory version of the Ground Controlled Approach Controller Training System (GCA-CTS) to the Naval Training Equipment Center (NTEC) in Orlando, Florida to demonstrate the feasibility of a speech recognition based training system.

Since that time, we have incorporated the speech technologies in other systems including the Automated Flight Training System designed for the Air Force and an Automated Command Response Verification System, a maritime safety system studied for the Department of Transportation. We have also continued to refine the original GCA-CTS in accordance with the results of experiments conducted by the Scientific Officer, Dr. Robert Breaux. We are presently building an experimental prototype version of the GCA-CTS for evaluation at the Naval Air Technical Training Center in Memphis, Tennessee. The remainder of this discussion will focus on this GCA-CTS work, which poses the most challenging user acceptance problems encountered to date.

The GCA-CTS. The GCA-CTS will employ commercially available hardware including two Data General Eclipse S/130 minicomputers, a Threshold Technology Threshold 500 speech preprocessor, a Federal Screw Works VS 6.4 Speech Synthesizer, and a Megatek MG552 Graphic Display Processor. The GCA-CTS will be designed to train students to interpret precision approach radar information and to give the well-defined verbal advisories which will enable the pilot to make a safe approach even in conditions of low visibility and without NAVAID receiving equipment in the aircraft.

The problem of training GCA controllers was originally chosen for study for several reasons. First of all, NTEC was interested in applying the concepts of automated adaptive training to air controller training. Until the advent of automated speech recognition however, machine-measurement of verbal task performance was not feasible. Automated speech recognition now makes it possible for the computer to determine the accuracy of what was spoken and grade student performance accordingly. With detailed performance assessment, it can automatically structure the training course to conform to the needs of the individual student. Secondly, present training for one student requires the attention of both an instructor and a pseudo pilot who controls a simulated radar target. This expensive resource allocation made the task a likely candidate for automation. Finally, since the verbal advisories are standardized and precise, the requirements seemed to be within the scope of the isolated word recognition art. Commercially available speech recognition systems are capable of recognizing a limited vocabulary of words or phrases, spoken in isolation, using reference patterns collected from the individual talker. A GCA controller training system therefore provided an ideal test bed for the concept of applying the AST to the training environment.

The system which is currently being designed will serve as an experimental task trainer for use by U.S. Navy enlisted men and women. It will provide relatively standard simulation of the radar environment and aircraft dynamics. No pseudo pilot will be needed because it will employ a pilot simulation whose ears will be the speech recognition capability and whose voice will be the speech synthesizer. Furthermore, the routine duties of the instructor will be simulated so that the GCA-CTS can provide instruction, present problems based upon the trainee's level of skill, supply performance assessments, and even administer and score a final examination. Simulation of these routine instructional duties will free the instructor to fill the

more demanding role of training manager and will provide him with the data to do this more effectively.

USER ACCEPTANCE CONSIDERATIONS

The GCA-CTS is an ambitious project both in terms of the scope of the required simulation and because of its reliance on state of the art technologies. The successful laboratory demonstrations have focused upon the technical risk areas and have revealed potential risks in the area of user acceptance. If the system proves difficult to use, irritating to listen to, or fails consistently to recognize the spoken advisories, the trainee's frustration will probably impede learning.

The following paragraphs describe many potential AST related user acceptance problems and present the diverse solutions which will be employed in the GCA-CTS. These include:

a. teaching the student to use the system properly

b. design of a training course which complements AST requirements

c. modification of state of the art speech recognition algorithms to accommodate the GCA vocabulary

d. addition of speech understanding logic to augment speech recognition

e. provision of effective feedback

f. use of discretion in the application of speech generation.

The very diversity which makes the topics difficult to weave into a logical progression illustrates the point that a concern for user acceptance must pervade all aspects of system design.

Training GCA-CTS Users. Proper use of the training system will be the first topic addressed in the training program. The rules of microphone placement and speech level production are critical to good speech recognition, but are easy to learn and employ. There is also a less obvious component of proper system use which has been labeled "learning to talk to the system." Introspection, if it may be admitted, suggests that the components of this art include confidence, naturalness of speech and consistency. The skill is easily acquired, yet time for acclimatization is very important to good speech recognition. During this period the trainee will be encouraged to experiment with the system to learn that it really can recognize what he says, and to discover the limitations inherent in automatic speech recognition. With this background, he will be ready to use the system effectively.

A Training Course Which Complements AST. There are many possible approaches to teaching GCA controller skills. The present course requires that the trainee master the entire vocabulary and try to put it to use the first time he plays the role of final controller. At first the instructor stands by and prompts him, and the pseudo pilot (a trainee also) can easily understand the advisories despite stylization problems and even word substitution errors. During the 5 days of training, errors decrease dramatically and the trainee emerges as a qualified controller.

This training philosophy is not suitable for an automated training system however. The automated system has certain strengths and certain limitations when compared to the human instructor. The automated system cannot match the verbalization error tolerance of the human listener for example, but it can be much more attentive than an instructor who is responsible for several students. It has the flexibility to simplify the environment and even stop the approach if necessary to illustrate its points. It can also contrive practice approaches which require use of only that material learned to date.

To take advantage of the tremendous power of the automated training system and to minimize the impact of its shortcomings, a training course has been designed by our training technologists to maximize the training effectiveness of the GCA-CTS. This training will be in accordance with the principles of errorless learning so the trainee should never learn to make mistakes. Furthermore, this training strategy will actually take advantage of what is often considered to be a drawback in state of the art speaker dependent speech recognition, namely the requirement to configure the system for the individual's speech patterns. Briefly, the training strategy involves dividing the GCA controller task into its component parts so that one topic can be presented at a time. The simulated environment will be manipulated to provide illustrative examples while the instructor simulation provides prompts. The trainee's speech patterns will be collected at this time and used to create the reference patterns for speech recognition. Thus as the trainee learns the procedures and phraseology, the system will be learning to recognize his voice. After this phase, the system will present tasks for the trainee to perform without prompts. These will be scored. Their purpose will be to allow the student to practice the new material and integrate it with the old.

This training strategy is expected to impact user acceptance in several ways. First, use of the system should prove rewarding.

Initial speech recognition problems will be minimized by the small vocabulary and thorough training so the goals set forth should be readily attainable. This initial success is expected to bolster the trainee's confidence in the system, thus, providing an important ingredient for future recognition success.

Secondly, the formidable task of configuring the system to recognize the large GCA-CTS vocabulary has been integrated with task training in a way that will be transparent to the user. User acceptance will not be hindered by an enmasse onslaught of phrase repetition requests. In addition, the strategy employed in speech pattern collection should ensure representative reference patterns which further promote speech recognition accuracy.

Finally, the automated adaptive system will devote all of its resources to teaching the individual user. It will ensure that each topic is mastered in a systematic way at the trainee's own pace. Any needed remediation will be provided automatically. Because of this highly individualized instruction, the trainee will be expected to attain proficiency in all of the GCA control tasks. The proficiency level attainable through thorough, systematic, task-oriented learning can be its own reward and should enhance user acceptance.

Augmentation of Speech Recognition Algorithms. In addition to these efforts to ensure good speech recognition by training the user carefully, the traditional speech recognition algorithms must be enhanced to accommodate the challenging vocabulary. The long vocabulary list of approximately 100 phrases contains many similar items and consists of both very long and very short utterances. Obviously this vocabulary cannot be modified in the interests of good speech recognition because it is defined by the FAA and used by all GCA controllers; instead, speech recognition will have to be modified.

In order to recognize the relatively large vocabulary in real-time and with high accuracy, the reference patterns will be partitioned by the phase of the approach, the previous transmission, the length of the phrase, and its intended destination. Using all these clues, the branching factor can be reduced to about 50 items in the worst case. This is similar to the branching factor tested successfully in the laboratory GCA-CTS.

To distinguish vocabulary items which vary only slightly, a scheme devised by Dr. Breaux and tested in the laboratory GCA-CTS will be employed. The technique involves comparing similar reference patterns to find those time slots which are significantly different. These rows are then correlated with the corresponding rows of the input feature pattern. The procedure effectively causes the pattern recognition algorithm to weight the distinctive portion of the utterance more heavily than the similar portions.

The GCA-CTS vocabulary, with its combination of long and short utterances, is a problem for the speech recognition algorithm, which depends on a time normalization scheme to extract relevant information from input utterances. The input is compressed into a pattern of standard length in which only those features which are reliably present are set. This compressed array is compared to similarly constructed reference patterns. The optimum length of these compressed arrays is related to the length of the input utterance. This becomes problematical when phrases as diverse as "eight" and "going further above glidepath" must be recognized. This will be solved by employing two sizes of reference patterns based on the length of the utterance. This may even prove helpful for vocabulary items of medium duration. On an experimental basis, both reference patterns will be used for these items and the results will impact the speech recognition module's measure of confidence in its decision.

The Requirement for Speech Understanding. To ensure user acceptance, the system must not make the mistakes which strict reliance upon speech recognition in this demanding environment could produce. There are sources of information in the simulation environment as well as a priori information which can be used to ensure the system understands what was spoken.

First of all, the speech understanding module will atempt to distinguish between controller errors and recognition errors, and will compensate for the latter. An example will help clarify this point. To the machine ear, the advisories "well above glidepath" and "well below glidepath" sound very much alike. Confusing these two is a gross error which the trainee is not likely to make. If such an error occurs, the system will assume the trainee has given the correct advisory. Trainee errors, on the other hand, are more likely to involve a confusion between contiguous aircraft positions such as between "above glidepath" and "slightly above glidepath." These phrases are readily distinguishable to the speech recognition algorithm, so the system will be able to score the incorrect advisory.

The speech understanding module will also compensate for typical trainee stylization errors whenever possible. GCA-CTS will employ isolated phrase recognition and therefore there must be slight pauses between the

digits given in turn commands. Because of their previous training, students are expected to forget this important requirement. Audio tapes reveal that a frequent error is a failure to pause before the first digit of a heading. Trainees will say for example, "turn right heading one (pause) five (pause) five." This utterance will probably trigger a low confidence recognition of "turn right heading" followed by correct recognition of two digits. Since the first digit is always the same, speech understanding will assume this error occurred if two reasonable digits follow a heading command and will compensate for it. In parallel development work, we are investigating an extremely promising limited continuous speech recognition algorithm called LISTEN (Logicon's Initial System for the Timely Extraction of Numbers) which would obviate the need for stylization of heading commands. The exciting results of the first phase of this work were presented at the December, 1977 Conference on Voice Technology for Interactive Real-Time Command/Control Systems Application at NASA, Ames Laboratory, Sunnyvale, California. The technique is being tested now in a laboratory training system, and we expect it will soon be ready for incorporation in the GCA-CTS and other operational trainers.

Finally, speech understanding will monitor the speech level to detect fluctuations significant enough to affect recognition accuracy. It will inform the trainee through the simulated pilot when transmissions become weak.

Effective Feedback. Despite the precautions taken to ensure errorless learning, consistently error-free performance in the complex GCA controller environment will probably remain a lofty ideal which can only be imperfectly realized. Therefore, effective feedback will be provided whereby the user can understand and learn from his mistakes. In this unique training environment, these mistakes will include stylization errors which cause recognition failures. Dr. Breaux added a replay capability to the laboratory GCA-CTS and it was found to be an effective feedback technique for procedural errors. In that system the speech synthesizer repeats the trainee's advisories and gives rule explanations when an error is encountered. He noted, however, that "message not understood" reports proved especially frustrating to the students. Many times a student was convinced that he had uttered the correct advisory but he had no way to argue with the computer or to understand why the recognition failure occurred. For example, he would remember that he had said "slightly above glidepath" but would not realize he had paused in mid-phrase, making the advisory unintelligible to speech recognition.

To add to replay's usefulness as a feedback technique and to reduce the frustrations associated with recognition failures, a speech input digitizer will be designed to record the trainee's advisories. The replay will then consist of an actual recording of the trainee's speech, synchronized with the visual display. From this, the student should be able to understand the cause of any recognition failures which occur. In addition to enhancing the student's acceptance of training system decisions, the replay will provide the instructor with an excellent tool. After the run, the student and instructor can review the run together. This will provide an excellent forum for discussion of such things as subtle points of style.

Use of Synthesized Speech. Synthesized speech is the ideal channel for some system outputs such as pilot responses and instructor comments. There are other situations in which it may be necessary to use it with discretion. For example, many persons adapt to its slightly artificial sound easily, but some express annoyance at having to listen to it for long periods of time and, therefore, its usefulness for presentation of instructional materials is limited by user acceptance considerations. The GCA-CTS design supports multimedia presentations of such materials, and synthesized speech, employed sparingly, is expected to enhance these presentations.

Use of the speech synthesizer could influence user acceptance in an indirect way as well. Verbal prompting is employed as an effective teaching technique in present controller training. The laboratory system also provides prompts using the speech synthesizer, but there is some debate as to whether or not synthesizer prompting is effective for good reference pattern collection. Some observe an unwilling mimicry of the speech synthesizer's inflection and timing. Others do not notice this effect. One thing is certain, reference patterns created from unnatural verbalizations do not provide the best possible recognition accuracy. The efficacy of the use of synthesized prompts in the collection of reference patterns will be carefully considered during GCA-CTS development.

SUMMARY

There are many challenging problems facing the system designer in the application of the automated speech technologies to simulation. We have attempted to show that effective strategies can be designed to employ these technologies in a training environment. These strategies include techniques for augmenting shortcomings both in the state of the art and in user performance to produce a system which can respond intelligently, be acceptable to the user, and can provide excellent training. These concepts will soon be ready for testing, and we look forward to a successful field evaluation.

ABOUT THE AUTHORS

MS. MARY HICKLIN *is Project Leader for the Ground Controlled Approach Controller Training System (GCA-CTS), experimental prototype, at Logicon, Inc. She has worked with all versions of the GCA-CTS for the last four years and was responsible for software design and implementation of the Automated Command Response Verification System, and for much of the implementation of LISTEN, Logicon's Initial System for the Timely Extraction of Numbers, a real-time continuous speech recognition system developed for the Naval Training Equipment Center. Her experience with performance measurement for automated adaptive trainers has included the development of the GCA-CTS performance measurement routines as well as implementation of the real-time performance measurement routines used in the air-to-air intercept and ground attack radar modes of the Automated Adaptive Flight Training System (AFTS). She holds a degree in biology from San Diego State University where her graduate work in systems ecology included the development of computer simulations of ecosystems.*

MS. GAIL SLEMON, *a member of the Technical Staff of Logicon, Inc., is currently working on design of the Ground Controlled Approach Controller Training System (GCA-CTS) experimental prototype. Past experience includes software system design and implementation of several different prototypes for the Micrographics Automated Intelligent Terminal (MAIT) which incorporates microprocessor controlled microfiche readers with hard copy and audio outputs along with keyboard and touch panel inputs for maintenance/training and other data base sequence defined applications. Prior to this, she was involved with System Engineering Level Evaluation and Correction (SELECT). Ms. Slemon received a B.S. degree in electrical engineering from Cornell University concentrating in computer science.*

A PROGRAM FOR DETERMINING FLIGHT SIMULATOR
FIELD OF VIEW REQUIREMENTS

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ABSTRACT

This paper discusses a test approach for determining the optimum field of view of a flight simulator visual system as a function of aircraft mission. The program is intended to provide the information needed to decide which portions of the aircraft's total field of view should be simulated and which can be disregarded. The approach consists of three phases: drawing board evaluation, aircraft ground testing, and flight testing. The procedure is described using the CH-46 helicopter as an illustrative example but it is applicable directly to any aircraft, fixed or rotary wing. Pilot qualitative ratings are obtained for each simulated visual configuration during specified flight maneuvers. Results from the CH-46 program indicated that a pilot/copilot oriented visual system limited the training potential for both crewmembers. The optimum configuration for the CH-46E operational flight trainer was a pilot oriented visual system.

BACKGROUND AND PURPOSE

1. Following the lead of commercial aviation, the U.S. Navy is rapidly expanding its use of flight trainers (Operational Flight Trainers and Weapons System Trainers) for pilot training and proficiency. This has been made possible by improved flight fidelity achieved through accurate duplication of actual aircraft characteristics and the addition of peripheral equipment such as audio systems, motion bases, and more recently, visual systems.

2. A visual system can significantly expand the types and quality of training possible in a flight simulator. For example, a realistic visual system provides the potential for training in the takeoff and landing regimes of flight -- two areas of high pilot workload and increased accident potential. However, this increased capability is not realized without cost as a visual system represents a significant percentage of the total expense of a trainer.

3. There are several types of visual systems for flight simulators. Each has its own particular advantages and disadvantages, as summarized in table 1.

TABLE 1.

Type	Description	Major Advantages	Major Disadvantages	Primary Areas of Applications
Computer Generated Image Night/Dusk System (Calligraphic)	TV type picture generated by a computer and special purpose digital processing equipment from a mathematical model.	High fidelity with real-world Low initial cost (1/2 to 1 Million) Low operating cost Wide FOV with multiple displays Scene changes made with software changes	Low light level display	
Day/Night System (Raster Scan)		Wide FOV with multiple displays Scene changes made with with software changes More scene content capability than night/dusk system	High initial cost (3 to 4 Million) Reduced fidelity in day scene compared with real-world Moderate operating cost	Takeoff and landing
Camera Model	Closed circuit TV picture of a scaled model of the problem area	High scene detail	Limited FOV and problem area Limited depth of focus Moderate initial cost for single channel (1 to 3 Million) Moderate to high operating cost	Low altitude slow speed maneuvers (Nap-of-the-earth flight)
Area of Interest	Camera model with high resolution target imagery superimposed on a low resolution sky/earth background	Almost unlimited FOV High resolution for target imagery	High initial cost (3 to 4 Million) High operating cost	Air to air combat

4. Ideally, the pilot flying a simulator would be presented a field of view (FOV) identical to that of the actual aircraft. However, due to cost and hardware limitations, current systems only present a limited portion of this total FOV. Program managers must assess the tradeoffs between training effectiveness and cost of a visual system when establishing the FOV requirements. Test and evaluation personnel can provide helpful information by determining which portions of the total FOV must be simulated and which could be eliminated, based upon mission requirements. This paper describes a test and evaluation method to give the program manager the information he needs to make an informed decision. No attempt is made to discuss in detail the advantages/disadvantages of visual system type or the effect of scene content and quality on pilot performance. Visual-system fidelity is discussed in detail in references (a) and (b).

COMPUTER-GENERATED IMAGERY VISUAL SYSTEM

5. The test approach presented in this paper applies directly to any visual system displaying less than the actual aircraft FOV. However, a Computer-Generated Imagery (CGI) system is used as the basis for discussion since the CH-46E Operational Flight Trainer (OFT) used a CGI system. A brief explanation of the CGI system is presented here to introduce terminology which is used later in this paper.

6. For a CGI system, a mathematical model of a particular visual scene is programmed into a computer. This scene must be mathematically defined in terms of a finite number of straight line segments or edges. The larger the capacity of the computer, the greater the number of edges available and, therefore, the more detailed the scene can be. The computer output is directed through Cathode-Ray Tubes (CRT's), similar to television picture screens. These CRT's are called windows, which is what they appear to be to the pilot in the simulator. The number of separate scenes the computer can generate simultaneously determines the number of channels a system can have. Thus, a simple system with two CRT's, one for the pilot and one for the copilot, each showing the same identical picture, would be a two-window, one-channel system. The copilot's window requires no additional computer capacity as its scene is just a repeat of the information put into the pilot's window. This two-window, one-channel system is called a pilot/copilot visual system, since the focal point of one display is the pilot's eye position and the focal point of the other display is the copilot's eye position. The pilot is not able to see the copilot's display nor is the copilot able to see the pilot's display.

7. A visual system with two CRT displays, each showing different scenes, is a two-window, two-channel system. If the focal point of both displays is the pilot's eye position, the system is called a pilot-oriented or pilot-only visual system. A display located in the copilot's front windscreen in a pilot-oriented system provides a distorted scene to the copilot.

8. The number of channels that can be used for a visual system is limited by the system's computer capacity and the size of the displays and supporting structures. Increasing the number of channels decreases the average scene content of each channel, as a given computer is capable of generating only a finite number of edges, and these must be divided among the channels. The fewer edges there are in a scene the less detailed and more cartoonish it will appear. Repeater windows which give the same picture as another require no additional computation capability, and in some applications, can be used to give the copilot or instructor a visual display without sacrificing scene quality.

DETERMINING FIELD OF VIEW REQUIREMENTS

GENERAL

9. If program cost restraints dictate a number of data channels and displays less than required to simulate the full aircraft FOV, then the optimum arrangement of visual displays should be determined by the flight test program presented in this technical paper. With results from such an approach, the program manager will be able to make meaningful decisions on cost and required visual system capabilities. In addition, squadron personnel will be able to determine what mission tasks should be included in their training syllabus. The amount of training degradation with limited displays can also be determined.

10. The mission and operating environments of the aircraft have an impact on the visual system FOV requirements. The FOV requirements can vary significantly among simulators for different aircraft due to the different mission environments of the aircraft. For an Anti-Submarine Warfare helicopter, adequate FOV representation of the shipboard landing task is essential for proper training. Reference (b) discusses an evaluation of the SH-2F Weapons System Trainer (WST) where there were training limitations due to inadequate FOV. For a Marine assault helicopter, duplication of the shipboard environment is also important, but the primary emphasis would be placed on FOV considerations relative to typical landing zones, particularly those in a confined area. Reference (c) discusses the evaluation conducted to determine the FOV simulation requirements for the CH-46E OFT.

TEST APPROACH

11. The test approach for evaluating simulator FOV requirements is logically divided into three phases: drawing board, ground test, and flight test. In these phases, configurations of candidate window displays are evaluated. As the program progresses through these stages, changes to display configurations become increasingly difficult, so attention given to the early stages can result in payoffs later.

Drawing Board

12. This is essentially a cut and paste "what do you think" sort of exercise in which pilots experienced in

the aircraft to be simulated and engineers familiar with visual system characteristics discuss possible visual display groupings and decide upon a number of candidate configurations to evaluate. To accomplish this, diagrams of the aircraft FOV from design eyepoint are drawn on a graph, which has vertical and horizontal FOV angles as ordinate and abscissa, respectively. An example of such a graph from the pilot's design eyepoint for the CH-46 helicopter is presented in appendix B. Graphs of this format can be produced readily by the FOV Evaluation Apparatus (FOVEA) described in appendix C. To evaluate a visual system for the copilot, FOV graphs must be created with the FOVEA from the copilot's seat since the presentation may not be the same from the different design eyepoint. The pilots arrange cutouts of the candidate window displays on the FOV graph. The engineers advise the group as to the technical feasibility of the proposed configurations, as limited by physical dimensions of the units, necessary overlap for adjacent units, or potential alignment problems. Generally, each pilot will have a different opinion on the relative importance of certain windows. This is due partly to individual differences in pilot technique and partly to the variety of missions each pilot has flown. Thus, if a multi-mission aircraft is being simulated, pilots experienced in each of the missions should be included in the evaluation. However, the evaluation group should be kept small enough to allow each pilot's opinion to be weighed and still come to an agreement within a reasonable amount of time. Once the candidate display configurations have been decided, it is appropriate to begin working directly with the aircraft.

Ground Testing

13. The first step in the ground test phase is to draw the candidate window display configurations on the aircraft windscreen. The FOVEA is very useful in sighting and documenting the appropriate window locations. Once a complete window display arrangement is sketched, the pilots make a preliminary appraisal. Generally, a number of minor relocations or adjustments are desired at this stage and they can still be accomplished with relative ease. At this stage it is also possible (and highly desirable) to eliminate some of the candidate configurations. From the sketches on the windscreen, amber cellophane (AMBERLITH) is cut into shapes to fit the canopy with openings where the proposed windows would be. An example used in the CH-46E OFT program is presented in appendix D. Using blue lens goggles (Device 1-F-4-b), the pilots can get a good idea of what the corresponding simulator FOV will be. The amber portions of the canopy windscreen will appear black while the pilot will be able to see through the display window cutouts and determine the suitability of each configuration. Modification to the configurations now becomes increasingly difficult but will continue to be necessary if an optimum arrangement is to be obtained. At this stage, it is still feasible to have a relatively large number of pilots participate in the evaluation, but in the flight phase, time and financial constraints will probably limit the number of evaluators.

Flight Testing

14. The final phase in determining the FOV requirements is to fly the aircraft with a minimized number of candidate window display configurations. Each configuration should be evaluated by at least two pilots for a series of specified mission tasks. An example of appropriate mission tasks for the CH-46E medium assault helicopter is contained in the evaluation sheet presented in appendix E. The acceptability of the FOV in accomplishing these tasks is rated by the pilot on a scale of 0 to 5, when 0 represents the degree of difficulty in performing a maneuver with no windows at all or as would be typical in instrument meteorological conditions and 5 represents the degree of difficulty in performing a maneuver with the actual aircraft FOV. Typically, each configuration will show strengths for some tasks and weaknesses for others. After flying each configuration, the results are evaluated and one of the configurations, or more likely a modification of it, is selected as the best. Time should be allocated in the test program to fly this "final" configuration to determine if it, in fact, offers everything expected of it. The project evaluation team will then be confident that the recommended configuration offers the best possible training potential within the constraints allowed.

FOV Considerations

15. As discussed in paragraphs 6 and 7, the visual system may be pilot or pilot/copilot oriented. If the decision for a one-pilot or two-pilot system is not made during the "drawing board" or ground test phases, it should be accomplished early in the flight program. It is not satisfactory to orient front windscreen displays for both pilot and copilot. A single front display will limit the copilot to forward flight profiles with little capability to fly curved approaches or to perform precision flight requiring outside periphial visual reference. Reference (c) reported that a pilot/copilot system for the CH-46E OFT limited both the pilot and copilot. The configuration consisting of a copilot front, copilot left side, and pilot right side was described by the copilot as more frustrating than useful when performing typical H-46 missions, with the single exception of a straight-in instrument approach to a roll-on landing.

16. An adequate vertical FOV is essential for a helicopter trainer. The lower edge of the front displays should be close to the bottom of the windscreen for adequate look-down capability during steep approaches and flares, precision hover, slow speed In Ground Effect flight, and ship landings. The initial "drawing board" position of the pilot's front display for the CH-46E OFT, reference (c), was shifted downward to enable the pilot to keep sight of the landing spot. The restricted FOV of the SH-2F WST, particularly in the lower look-down angles, created problems in precise hover, low-speed flight, and frigate landings as reported in reference (b). Reference (c) reported that flight test results verified the pilot chin window display was important in the proposed H-46 OFT visual system when the helicopter was near the ground and moving.

17. Items that should be considered for the top of the displays for helicopter OFT's include the horizon in forward flight and the rotor tip path plane for ground operation or confined area landings. Simulation of maneuvers involving large forward control inputs and typical autorotative entries require a FOV display above the normal level flight horizon.

18. Horizontal FOV requirements are also dictated by mission requirements. Flight operations requiring 360 deg turning patterns (i.e., plane guard, Magnetic Anomaly Detection trapping, etc.) or both left- and right-hand shipboard approaches with traffic monitor will require substantially more horizontal FOV than forward flight cruise and straight-in landings. Visual information aft of the pilot or copilot 90 deg position in the CH-46 provided only low priority information, as reported in reference (c).

Safety Precautions

19. As in any flight test program, certain safety considerations should be addressed during the flight test phase. The amber cellophane installed in the windscreen of the aircraft causes negligible degradation of visibility in clear or cloudy daytime light conditions but seriously hampers the pilot's visibility at night. Therefore, these flights should not be flown at night. Also, the safety pilot should not use sunglasses or a shaded visor during the evaluation flights since these also restrict visibility through the amber cellophane. Since some window display candidate configurations may severely restrict FOV in some quadrants, the crew chief should be specifically briefed to pay particular attention to these quadrants and advise the pilots of traffic or obstacles.

SUMMARY

20. This test approach for determining flight trainer visual system FOV requirements, described using the CH-46E OFT as an illustrative example, can be applied directly to any aircraft, either fixed or rotary wing. It provides the evaluation team, program manager, and squadron personnel with information on the impact of FOV on mission training potential. There are other visual system considerations beyond the scope of this type of evaluation which have a significant impact on visual system fidelity and training potential. Among these are scene content and quality, image realism, aliasing tendencies, and visual system/trainer interface. Defining simulator FOV requirements is only one part of the problem but an important early step in the process.

APPENDIX A

REFERENCES

(a) NAVAIRTESTCEN Technical Memorandum 77-1 RW of 27 April 1977, A Program for Increased Flight Fidelity in Helicopter Simulation.

(b) NAVAIRTESTCEN Technical Report RW-11R-77 of 31 March 1978, Flight Fidelity Evaluation of the SH-2F Weapons System Flight Trainer (Device 2F106).

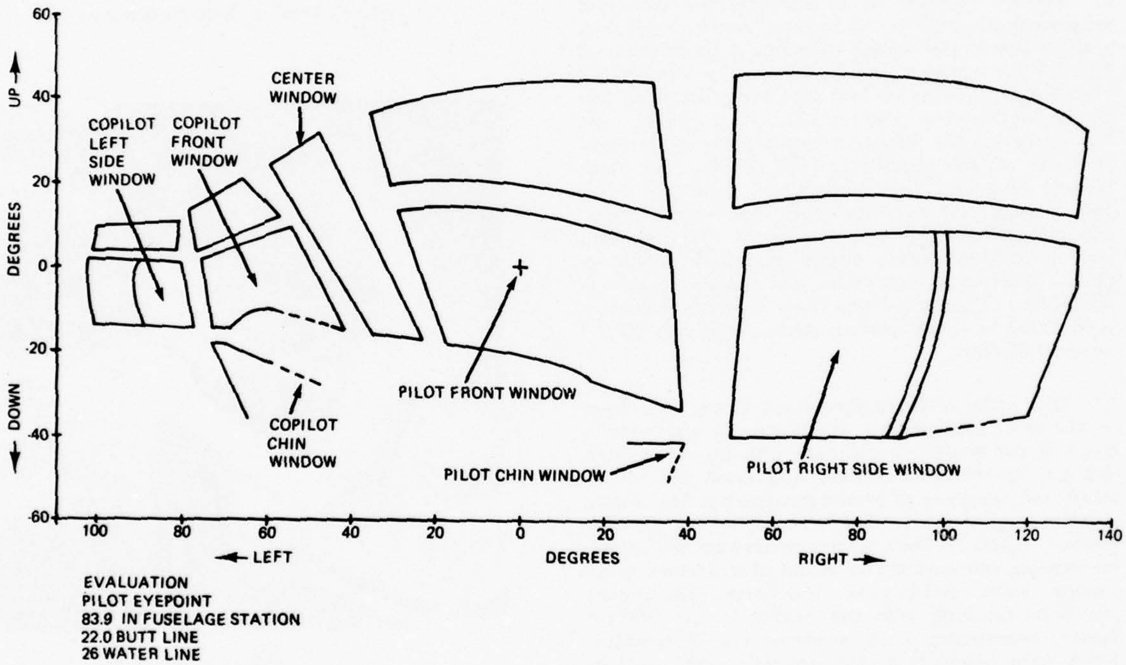
(c) NAVAIRTESTCEN Report of Test Results RW-41R-77 of 8 March 1978, CH-46E Operational Flight Trainer Evaluation, First Interim Report.

RELATED ARTICLE

(d) NAVAIRTESTCEN Technical Memorandum TM-78-2RW of 12 April 1978, Environmental Requirements for Simulated Helicopter/VTOL Operations from Small Ships and Carriers.

APPENDIX B

CH-46 COCKPIT FOV FROM PILOT'S EYEPOINT



APPENDIX C

FIELD OF VIEW EVALUATION APPARATUS

1. The Field of View Evaluation Apparatus (FOVEA) is an instrument capable of measuring, recording, and graphically plotting the angular subtense of objects relative to the design eye reference point of crew stations. Its principal application is the measurement, for evaluation and verification purposes, of the external FOV of aircrew stations. It is designed for use in both mock-ups and actual aircraft crew stations and generates the FOV plots required for verification of data submitted in accordance with MIL-STD-850B. It also has utility in the evaluation of visual obstructions to the line-of-sight to controls and displays, documentation of simulator visual system FOV, verification of control/display location relative to the primary visual areas for caution/warning displays, photographically recording from the desired viewing position (design eye), and identification of deficiencies or enhancing characteristics during FOV evaluation tests.

2. FOVEA consists of a commercially available programmable desk-top calculator and X-Y plotter, a servo-driven TV sensor element, a TV monitor, a joystick for sensor pointing control, and associated electronics on adapter brackets for positioning the sensor in the crew station seat. A magnetic tape cassette recorder and hard-copy printer are integral features of the calculator and provide for data storage and hard copy printout of measured data. The system software provides for initial setup alignment, sensor positioning error compensation, and selection of plotter output options of rectilinear plots, equal area projection, and tangent plots for generation of landing vision data. A polaroid camera is included to obtain photographic records of the TV monitor display.

3. Test setup requires placement of the TV sensor on the crew station seat pan (figure 1) and adjustment of the sensor to coincide with the design eye location for the crew station. Alignment procedures verify the accuracy of sensor positioning. The sensor pointing angle is controlled remotely by the joystick control (figure 2). Data were acquired by the operator tracing the outlines of visual obstructions (e.g., canopy rails, windscreen bracketry, instrument panel) by tracking with the center of the FOVEA sensor, represented by a cursor on the TV monitor. After data acquisition, the desired output options are selected via controls on the calculator and the data are presented graphically on the X-Y plotter.

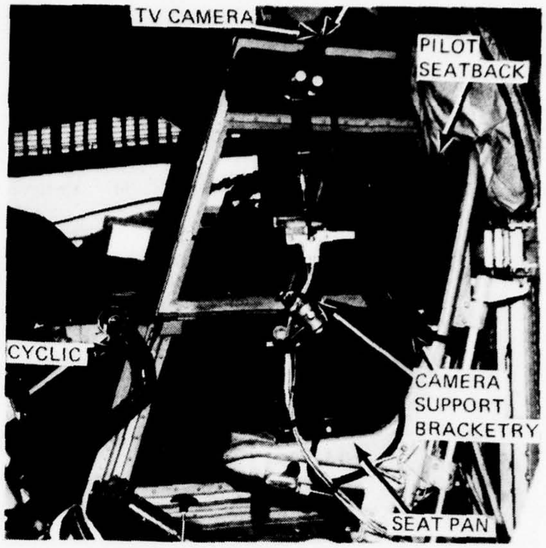


Figure 1
FOVEA TV Camera Mounted in Pilot's Seat of H-46 Helicopter

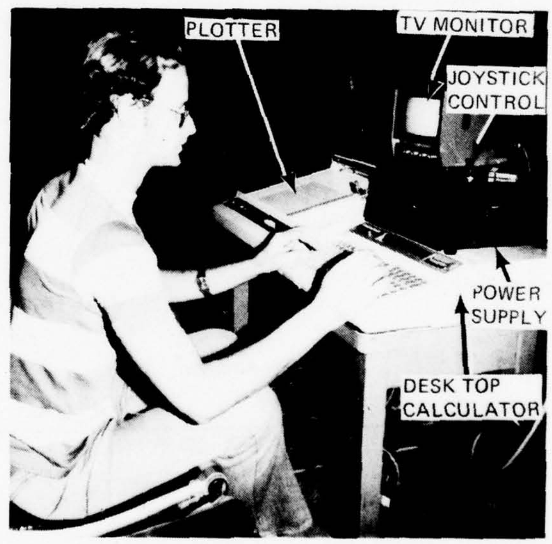
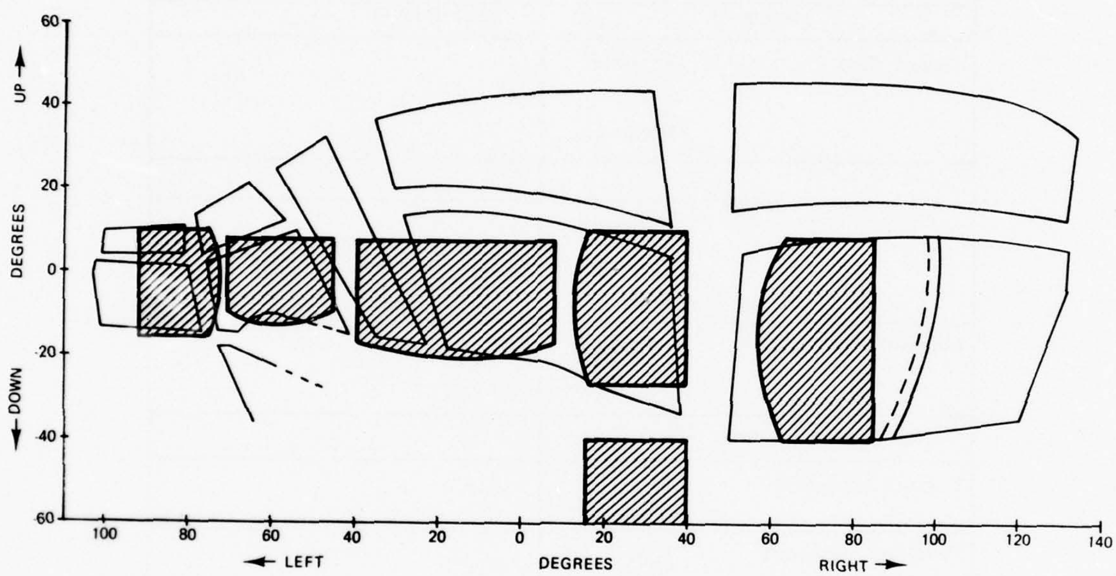


Figure 2
FOVEA Control Equipment Positioned in H-46 Helicopter Cabin

APPENDIX D

COCKPIT LAYOUT FROM PILOT EYEPOINT FOR
PROPOSED SIX-CHANNEL, SIX-WINDOW
CGI VISUAL SYSTEM FOR CH-46E OFT



APPENDIX E

SAMPLE MISSION TASK EVALUATION SHEET
(USED IN CH-46E OFT VISUAL SYSTEM EVALUATION)

<table>
<tr><td>Aircraft Type</td><td>BuNo</td><td>Time T.O.
Time Land</td><td>Date</td><td>Flight No.</td><td>Card No.</td></tr>
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Land GW</td><td>T. O. CG
Land CG</td></tr>
<tr><td colspan="3">Visual Test Configuration</td><td colspan="3" rowspan="2">Aircraft Configuration</td></tr>
<tr><td colspan="3">Weather   Wind   Visibility</td></tr>
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Aft
Left
Right</td><td colspan="3"></td></tr>
<tr><td colspan="3">Hover</td><td colspan="3"></td></tr>
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Aft
Left
Right</td><td colspan="3"></td></tr>
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Left Bank
Right Bank</td><td colspan="3"></td></tr>
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<tr><td colspan="2">Normal Approach</td><td>Left
Right</td><td colspan="3"></td></tr>
<tr><td colspan="2">Precision Approach</td><td>Left
Right</td><td colspan="3"></td></tr>
<tr><td colspan="2">LPH Approach</td><td>Left
Right</td><td colspan="3"></td></tr>
<tr><td colspan="2">360 deg</td><td>Left Turn
Right Turn</td><td colspan="3"></td></tr>
<tr><td colspan="2">Autorotative Approach</td><td>Left
Right</td><td colspan="3"></td></tr>
<tr><td colspan="2">Autorotative</td><td>Entry
Recovery</td><td colspan="3"></td></tr>
<tr><td colspan="3">Quick Stop</td><td colspan="3"></td></tr>
<tr><td colspan="3">External Pickup</td><td colspan="3"></td></tr>
<tr><td colspan="3">External Drop</td><td colspan="3"></td></tr>
</table>

ABOUT THE AUTHORS

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COMPUTER IMAGE GENERATION OF CURVED OBJECTS FOR SIMULATOR DISPLAYS

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INTRODUCTION

Vehicle simulators have become a standard tool in the training of aircraft pilots and other vehicle operators because use of the actual vehicle can be prohibitively expensive and dangerous. In addition, training scenarios that might be undesirable to represent in reality can be simulated in a controlled environment. Thus, with simulators, pilots can train for air-to-air combat or missile evasion and can practice repeated "landings" on an aircraft carrier in heavy seas. In this way, astronauts were able to become proficient at landing on the moon long before the lunar lander had reached the launch pad.

Among the most important training cues in the vehicle simulator is the visual display. Traditionally, simulation of motion has been provided by large model board systems viewed through television. As the trainer pilot controls his vehicle motion in "simulation space," a TV camera ranges over the scene on the model board and transmits a view corresponding to his simulated perspective. In general, however, the model board technique has been found to be too limiting. To cover the large ground areas needed for high-speed aircraft simulation, a model board of unwieldy size would be required. A change of scene requires an entirely new model board, and board construction and alteration are very expensive. There are also optical problems such as depth of focus. Finally, certain physical scenarios are awkward or impossible with model boards. Low-level helicopter flight among trees, actual touchdown and motion under objects are examples. Bombing missions, missile firing, and refueling are others. The basis of all these problems lies in the physical nature of the model board scene.

Computer Image Generation (CIG) avoids these problems by using an abstract scene stored in a computer memory in mathematical form. Many scenes can be stored, and changes can be made easily. Any environment can be simulated, and optical problems are nonexistent. A pilot can fly under bridges, fire weapons, bomb portions of the scene, and even crash without consequence. For these reasons, CIG is becoming more and more the standard method for simulator displays.

STATE OF THE ART IN CIG

The basic problem with CIG is that dynamic displays require high-frame rates, necessitating the production of an entire picture every thirtieth of a second. For complex scenes, this means that massive amounts of computation must be accomplished in a very short time. From a large global scene stored in computer memory, the portion visible to a pilot in a given frame time must be determined, transformed according to the pilot's perspective, and projected onto the image plane (as realized by the TV monitor). All this must be done continuously at TV frame rates and in accordance with the raster scan format of the monitor. All hidden surface portions must be properly occluded and point-by-point illumination of each visible surface realistically represented. Any time delay, computation error, or misrepresentation of a scene feature will adversely affect the simulation and the training.

To accomplish the high-computation rates needed, the current state of the art in CIG employs a technique we will call the "Planar Patch Method." This technique simplifies the problem by reducing any arbitrary scene to an approximation consisting of straight edges and flat surface patches (Ref. 1). The advantage to the Planar Patch Method is that it reduces computations to the simplest level possible. Since location of all projected edge points are calculated by intersection with the scan lines, the technique need handle only simple intersections between straight lines. Since all surfaces are flat, shading along a surface between edge points can be filled in with a constant value. If the scene being modeled consists totally of flat objects, such as a runway scene with parallelepiped buildings, the Planar Patch Method provides realistic simulation. Furthermore, if a limited number of edges are sufficient to describe the scene, this technique can achieve TV frame rates by use of special-purpose hardware arrayed to "pipeline" the many simple computations.

The problem with the Planar Patch Method is that it is not designed to model curved surfaces. Any representation of a curved object by a finite number of straight edges and planar patches can only be an approximation (Fig. 1). The appearance of artificial edges and shading discontinuities

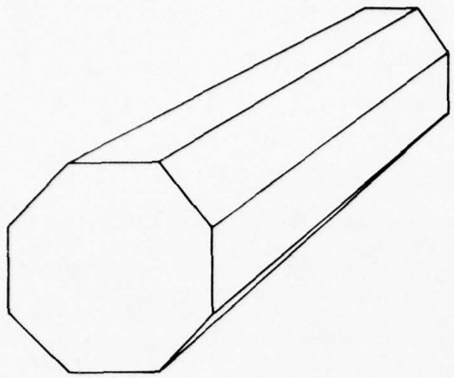

Figure 1. Planar Patch Representation of a Cylinder

in supposedly smooth surfaces (such as oil tanks or aircraft fuselages) degrades the visual simulation to an unacceptable level. To avoid this, two adjustments must be made. First, a disproportionate number of edges must be assigned to each curved object, and second, shading discontinuities between planar patches must be smoothed over by interpolation. The result is increased complexity in both the data base and the computation algorithms. Thus the Planar Patch Method, which represents a simplification in the generation of flat images, must backtrack into increasing complexity to generate curved surfaces. It should also be noted that no matter how well the shading is smoothed to hide edges interior to the object silhouette boundary, the boundary itself will always show an "edginess" for any finite number of edges used.

To overcome the problems inherent in the Planar Patch Method and to advance the state of the art in CIG, the Research Department of the Grumman Aerospace Corporation has undertaken a project to develop techniques that will allow realistic, real-time generation of images of curved objects.

CIG OF CURVED OBJECTS

There are two techniques currently in use for generating realistic images of curved surfaces. The first technique is the Bicubic Patch Method, which models a curved object by a set of third-order surface patches. Work in this area has been pursued at the University of Utah (Ref. 2) and produces very realistic renderings of sculptured surfaces such as bottles and wine glasses. Because of the complexity of the bicubic patch equations, however, the data base is extensive and complicated. More importantly, each image picture element must be examined and a costly subdivision of each patch computed. The Bicubic Patch Method, therefore, has not proven applicable to real-time CIG.

The second curved surface technique, which we call the Ray Tracing Method (RTM), uses second-order surfaces to define objects (Ref. 3). Whole objects can be modeled by only a few such surfaces, sometimes by just one second-order surface with one or two planar surfaces (Fig. 2). Because the second-order surface is the simplest surface that can model true curvature, and because so few surfaces are needed to represent objects, the RTM offers the potential for the simplest data base and simplest computation load for generating curved surface images. For this reason, we have used the RTM as the basis for our study.

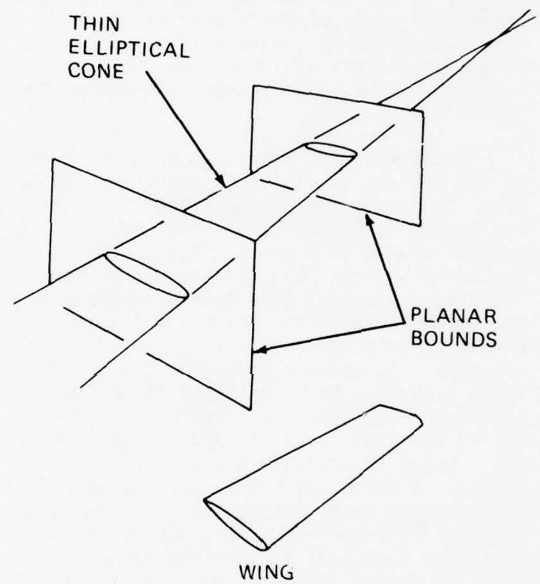

Figure 2. Ray Tracing Method (RTM) Representation of a Wing

The basic RTM algorithm works as follows. A scene space consisting of an arbitrary number of objects each composed of first- and second-order surfaces is defined in computer memory along with a defined illumination vector (Fig. 3). From a specified eye point, a ray is traced through each pixel in the image plane. A test is made for intersection of the ray with each surface of each object in the scene space. The point on the surface nearest to the eye point is the point visible at the given pixel. Shading intensity is determined by calculating the surface normal at the visible point and computing the cosine between the normal and the illumination vector. Since a typical scene would require many objects and would be presented on a display consisting of over 500 points

on over 500 scan lines, it can easily be seen that the brute force RTM requires far too much computation to achieve real-time rates. However, inherent in the basic concept lies the potential for drastically reducing the number of calculations.

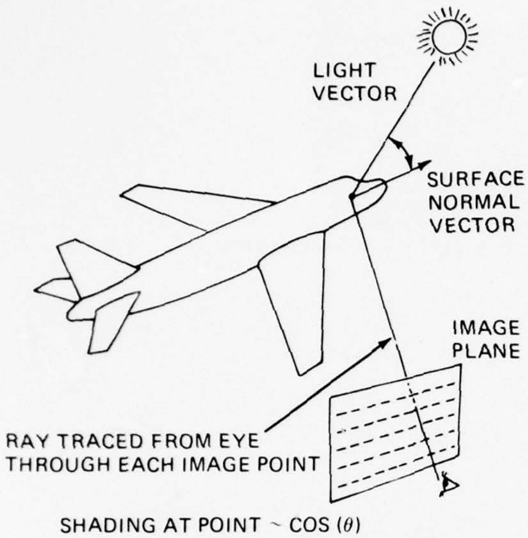

Figure 3. RTM Schematic Diagram

MODIFIED RTM FOR REAL-TIME CIG

We have made major modifications to the basic RTM which eliminate the pixel-by-pixel ray tests and thereby reduce computation time drastically. Although the details of our algorithms are proprietary, the essence is as follows. We calculate only the high-order scene information with complete precision and fill in the low-order information with a smooth approximation. Since the high-order information represents only a small fraction of the total image, the effectiveness of this approach is obvious. The test scene in Figs. 4 and 5 illustrates our procedure. The KC-135 is composed of 21 objects. The fuselage includes 5 objects, portions of a cylinder, a cone and 3 ellipsoids; the 5 aerodynamic surfaces are each made of a thin bounded elliptical cone; each engine and engine mount is a bounded ellipsoid; the boom is a cylinder; and the rudderators are thin elliptical cylinders.

Included in the algorithms are routines to remove all hidden surface portions. The visibility logic works on two levels. First, all hidden surface portions on individual objects are removed; then all surface portions occluded by other objects are removed.

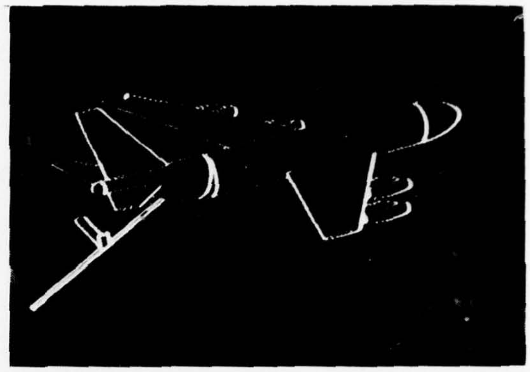

Figure 4. Modified RTM Scene of KC-135 Showing High-Order Information Only

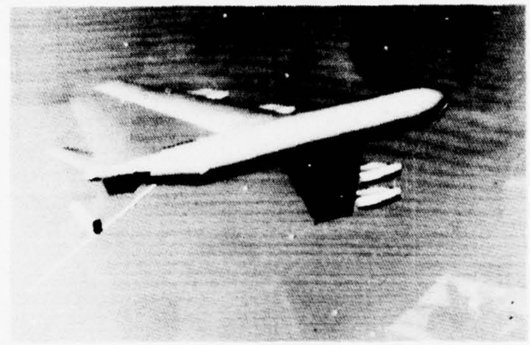

Figure 5. Modified RTM Scene with Low-Order Information Filled in

The image generation procedure is divided into two parts. First, the frame processor transforms the scene objects to viewer perspective, extracts the high-order information, and performs the intraobject visibility logic. Then the scan-line processor performs the interobject visibility and fills in the low-order information. Computation time for the boundary image in Fig. 4 was two seconds; the shaded aircraft image in Fig. 5 took six seconds. The program was run on a general-purpose minicomputer (Data General Eclipse) with no special-purpose hardware. A comparison test of the brute force RTM took three hours to generate the shaded aircraft. This represents three-to-four orders of magnitude improvement with our refinements.

Figure 6 shows a different view of the KC-135 scene, and Fig. 7 shows a sequence of images representing a refueling mission. A ground plane and sky background have been added for more realism. It should be noted that the Planar Patch Method would require over 1000 straight edges to model the KC-135 and would result in considerable loss in

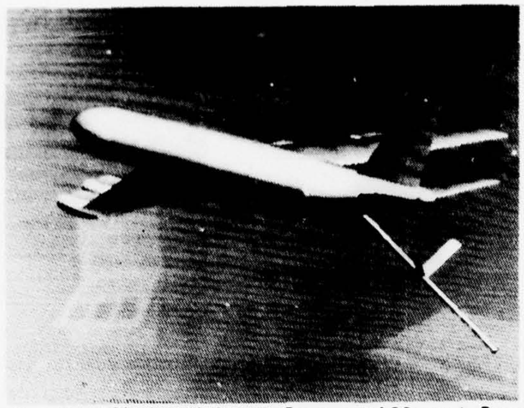

Figure 6. Modified RTM Scene From a Different Perspective

Figure 7. Refueling Sequence

realism as the viewer approached the aircraft. Indeed, no finite number of straight edges could duplicate the fidelity of the KC-135 refueling scene.

NONVISUAL SENSOR SIMULATION

Because the RTM uses smooth surfaces, it will model nonvisual sensors such as radar with the same data base used for visual images simply by changing the illuminance/reflectance algorithm. Figure 8 is a sequence representing a simulation of synthetic aperture radar images of the KC-135 scene. Arbitrary levels of resolution can be modeled to simulate real radar systems. Note that this type of radar simulation would be impossible using the Planar Patch Method because the large number of surface discontinuities would create an artificial scattering effect.

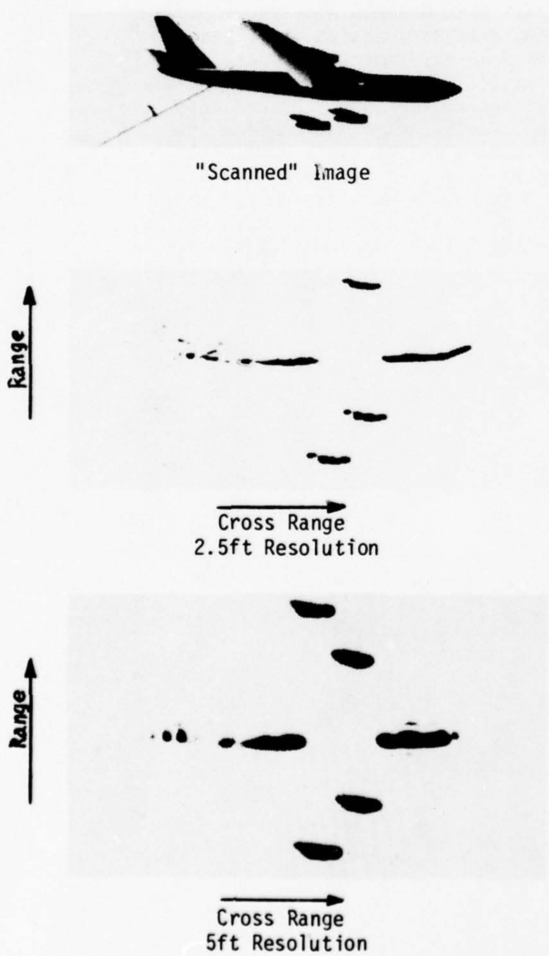

Figure 8. Synthetic Aperture Radar Simulation

Because the RTM data base consists largely of whole volumes rather than surface patches, infrared (IR) images can be modeled by a simple extension of the data base. For example, an oil tank could be represented visually by a single cylinder section whose image is shaded according to the standard reflectance model. For IR simulation, the data base would be extended to two cylinder sections, one for the oil-filled portion and one for the empty portion of the tank (Fig. 9). Shading would be determined according to a radiance model, and each of the two tank sections would have its own radiance parameter. Day-night changes would be effected in the same data base by radiance parameter changes.

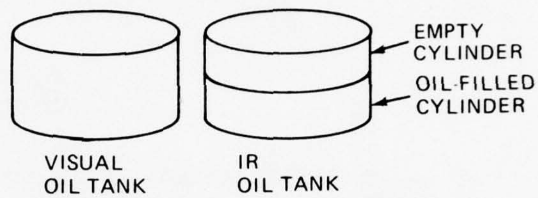

Figure 9. Infrared Simulation

DISCUSSION

In comparison to the Planar Patch Method, the modified RTM has the basic disadvantage that the second-order surfaces and curves require more complicated computations. This disadvantage can be minimized (and perhaps removed entirely) by breaking down the more complex calculations into a series of simple steps that can be implemented in special-purpose pipeline hardware. We are currently studying such a configuration for the scan-line processor algorithms as well as a parallel array of microprocessors for the frame processor. It must be remembered that even the Planar Patch Method requires specially designed hardware to achieve TV frame rates.

In contrast, the advantages of the modified RTM are numerous. First, curvature is represented faithfully, no matter how close the viewer is to the surface. No smoothing is required across patch edges because there are none. Secondly, because objects tend to be represented as whole bodies, the data base is smaller, simpler, and easier to construct. Thirdly, because surfaces are represented smoothly without discontinuities, nonvisual sensors such as radar can be modeled using the same data base.

FUTURE WORK

We are developing a conceptual design of special-purpose hardware and microprocessors to implement the algorithms at TV frame rates. We will incorporate refinements to handle more complex objects and algorithms to generate texture.

ACKNOWLEDGEMENTS

The author wishes to thank Mr. Robert Rulon for his aid in defining the KC-135 test scene and Dr. Stephen Hsiao for contributing the radar images.

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THE AWAVS DATA BASE FACILITY — A COMPREHENSIVE PREPARATION PACKAGE

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JOHN L. BOOKER, Naval Training Equipment Center

INTRODUCTION

A complete data base creation facility has been developed by General Electric for the Aviation Wide-Angle Visual System (AWAVS) computer image generator (CIG) at the Naval Training Equipment Center in Orlando. This facility provides both on- and off-line capabilities to attack all facets of the data base development problem. While an off-line data base preparation device alone will improve the initial ability to digitize and create visual data bases, the task is incomplete and provision must be made for rapid on-line viewing and alteration of a new data base to achieve successful environments in a reasonable length of time. An off-line facility without on-line support tools is like designing an aircraft without a wind tunnel. Results are known only when it is flown, and any modifications must be done statically (off-line).

REVIEW

Too often, CIG systems have turned into a fly now, pay later operation when an attempt is made to modify the existing operational data bases or add new training environments. The pay aspect takes the shape of two major costs: one, the slow turnaround time of developing and refining new data bases to a usable form; the second is system time required on the on-line computer for actually running the off-line software and correcting programming and data errors. Consequently, CIG system procurements are increasingly recognizing the importance of having some type of data base facility to support full-time utilization of the capabilities inherent in a completely configured CIG system.

The AWAVS system is a two-channel CIG system with many developmental features needed in the research environment for which it was intended. One of the unique features of this system is the data base development facility which is the subject of this paper. Recognition of requirements for a complete set of data base creation tools resulted in the design of the first data base creation package incorporating not only off-line equipment and software, but also complementary on-line hardware additions which allow effective utilization of the off-line facility.

A brief review of the major AWAVS components is necessary to provide a background for discussion. The AWAVS CIG structure, shown in Figure 1, is comprised of three (3) major systems: an on-line system, an off-line data base creation facility, and a non-real-time camera station.

The on-line system shown in Figure 2 contains a DEC PDP-11/55 GP computer with card, tape, disc and line printer peripherals, a special-purpose CIG processor built by General Electric, and an Instructor's Console with TV monitors and joystick control. Special features, such as raster mapping for the wide-angle dome display, multiple resolution rates (525, 825, or 1023 raster lines), dynamic update of on-line storage, face level of detail blending controls, independent viewpoint control, and collision detection provide a multiple application research capacity never before incorporated in a single CIG system. These features and the basic on-line architecture comprised of Frame I, Frame II, and Frame III organizational structures similar to other CIG systems covered in papers referenced herein will not be discussed further in this paper.

The off-line data base creation facility shown in Figure 3 contains a digitizing table, an Applicon caligraphic storage tube display and software system, and a VAX-11/780 computer. It is a completely stand-alone facility that allows entire data bases to be digitized, viewed and corrected in caligraphic display, and formatted for real-time operation with no on-line system time required.

Also shown in Figure 3 is the AWAVS camera station consisting of a Dicomed recording monitor with still and moving film capabilities connected to the VAX 11/780 computer. It is operated in non-real-time from a software program that simulates the complete on-line system. The camera station allows various algorithm changes to be implemented and studied without the necessity of hardware changes. It is a general research tool that allows non-real-time generation of still photographs and motion film clips of high-detail visual environments far exceeding the capacity of any existing real-time hardware. "What if" questions about data base content and image generator requirements can be answered without

hardware prototypes. Operational characteristics for image generator specifications of future training devices can be determined by project team personnel well in advance of prototype development. This type of capability was never required of past CIG systems designated for training installations.

DEVELOPING A DATA BASE

In any CIG system, the ultimate product and final subjective measure of the system is the data base and the realism of its visual offspring. This being the case, the system tends to be judged largely by the effectiveness of its data base. Consequently, the data base becomes the instrument of compromise. In the final development, it must be bent, shaped, and manipulated to produce the most pleasing dynamic scene while being constrained by and compensating for whatever are the particular system hardware and software restrictions.

An off-line data base creation facility (functionally shown in Figure 4) will improve on the time and effort required to produce the first pass data base through use of interactive graphic software and library retrieval of stored proto-objects. File management facilities allow basic object definition to be accumulated on mass storage, then retrieved for direct utilization or modification in a visual environment. However, the result must be critiqued on the actual display monitors in order to determine the final necessary modifications and enhancement. Off-line facilities with some type of visual feedback (Applicon caligraphics for AWAVS) can eliminate some of the more obvious errors, but the final judgement must be done in a real-time dynamic movement display with true perspective and correct system color characteristics.

The net result is that development of a new data base takes on an organic aspect starting with the original digitized kernel and being pruned and culled during the necessary iterations of viewing the results on-line, modifying the data off-line, and then reviewing the modifications on the on-line system.

Since the final raster video observed by the designer, in general, does not contain any information to locate a particular object or face from its off-line source (and as data bases become ever larger, the connection becomes more tenuous), the designer is reduced to viewing a scene and making notes as to which model/object/face requires modification based on personal knowledge of how that data base is constructed. The designer must then return to the off-line facility to locate the proper card deck, disc file etc., make the assumed changes and review the scene to determine the results. This is a feasible undertaking for specialized data bases or easily identified models, but becomes almost an impossibility for misplaced vertices, lights, objects or generally nondescript terrain.

ADDING INTERACTIVE CONTROLS

In order to maximize the contribution of an off-line creation facility, it is necessary to design the special processor hardware with a "tracing" ability in order to locate the off-line source of displayed raster images. Without this capability, the bulk of data base preparation effort stays in the "craftsman" category requiring excessive iterations during the real-time viewing-modification cycle and undermining the advantages of an off-line data base creation facility.

This tracing ability of the hardware must be designed to provide all of the hooks and handles that are necessary to completely identify and locate each specific item of an environment. The structure of each system will dictate the unique hooks and handles required to trace the format of model/object/face groupings and associated addressing schemes.

The AWAVS system has data bases organized into a block/model hierachy (Figure 5) with a given data block containing from 1 to 128 models and each model capable of being modeled for 8 separate levels of detail. Each level of detail is an organization of objects, each object is a set of faces, and each face a set of vertices. The entire environment is processed by the special-purpose processor hardware using a pointer system with all pointers relative to the entire data block starting at address zero. Each data block is assigned by the on-line computer a starting address which is added as an offset to all subsequent pointers of that data block.

In order to relate raster information back into this data structure, it is first necessary to produce a visible raster mark on the display. This is done on AWAVS, shown in Figure 6, by inserting a pointer into the video processing portion (Frame III) of the hardware with computer-controlled I, J values; I being the raster line value and the J the element value. This marker has a dedicated color number, so it can be changed as needed (white for night scenes for instance) and

always has priority over all faces in the scene. The pointer is thus moveable under operator control and can be placed over any face in a given scene.

The hardware face number of the face being "touched" by the pointer is captured by special hardware activated by the pointer controls. This hardware face number can then be fed to the front-end hardware (Frame II) that is processing the on-line environment data blocks. There is special search hardware built into the Frame II section that uses this hardware face number as a key and through several raster frames of processing captures first the object environment face number, then the active model number, then the environment model number and level of detail, and finally the data block from which that particular face originated. Each specific number is a reference provided during the off-line construction of that data block and the captured set is sufficient to uniquely identify an object. All captured information is held in data registers that are accessible to the on-line computer.

Since point lights, unlike edges, are not generally part of a visible face, it was necessary to design a point light lasso feature. In this mode of operation whenever the end of the pointer is within a 4 x 4 pixel range of a point light, that particular point light is captured by special hardware that will trigger the process described previously for edge faces.

SPECIAL INTERACTIVE SOFTWARE

At this point, with the block, model and face locations captured, the guess work has been taken out of modifying a specific feature and a skilled operator could make any desired changes, but still in an off-line mode requiring further review and appraisal of the results. For the AWAVS system, however, a special interactive software package was developed to close the loop in data base modifications. With this software package, which is capable of "flying" the pointer using the debug joystick, it is possible to not only collect the information but to then edit and add to the data base under review, and see the results in real-time as indicated in Figure 7. By temporarily changing vertices in the Frame II data storage, edges can be moved and point lights relocated. Face colors can be modified, levels of details deleted, added or adjusted and general environment editing accomplished in operator real-time mode.

More extensive data base modifications, such as translating and rotating entire models are accomplished by temporarily assigning the indicated model to a moving model coordinate system. The model can then be flown under joystick or terminal control to a new position and attitude in the environment. If lights, edges, or faces are to be created to be added to the environment, the affected model will be transferred to an unused section of memory and pointers adjusted accordingly in such a manner as to provide the additional memory slots necessary to contain the newly created data.

The operator interfaces with the interactive software using simple edit commands and receiving prompting and requested information (vertex locations, colors, etc.) from the program. He also receives visual cues on the screen such as faces touched by the pointer will flash and captured point lights will blink in addition to the inestimable information gained by seeing the immediate result of a modification. If a particular modification does not produce desired results, it can be returned to the original state or otherwise further adjusted.

Once a series of modifications has achieved the results desired by the operator, he can terminate the interactive process and request a change summary. This will result in providing a step-by-step listing of all changes that were produced during the data base review session.

Since the on-line changes were temporary, this change listing is then input to the off-line facility to create the final repacked data base. This procedure is necessary for two reasons. One is to maintain configuration control of the data bases via the off-line facility. The other is to eliminate from the on-line interactive software those data tasks, such as data packing and priority separation plane computation, that are not necessary for quick visual checks of the modifications, but are too time consuming to allow adequate man-machine response times.

ILLUSTRATION

Figure 8 shows a scene from a data base under development. The modeler has activated the pointer and is using it to identify a face to be changed. The interactive program provides the modeler with a printout identifying this as face #173 of model #1, first level of detail, environment data block #4. The modeler could request additional information if desired such as, the vertices defining the face, color code of face, etc. The modeler wishes to develop a low-detail version of this model so types in a deletion command which will cause the program to restructure

the data to inhibit processing of that face. Figure 9 shows the changed scene, validating in an immediate interactive manner that the desired result was achieved.

SUMMARY

The result of the overall AWAVS data base creation package is to provide a complete set of tools for the designer such that he can quickly create and digitize a new data base on the off-line facility, completing a modicum of first level debug with the caligraphic display. He can then review and modify the data base on the on-line system in real-time with a high degree of confidence that the final off-line product will produce the intended results. The interactive software package reduces the on-line system time required by increasing the ability to identify objects to be changed and significantly reducing the number of iterations necessary to achieve the final result.

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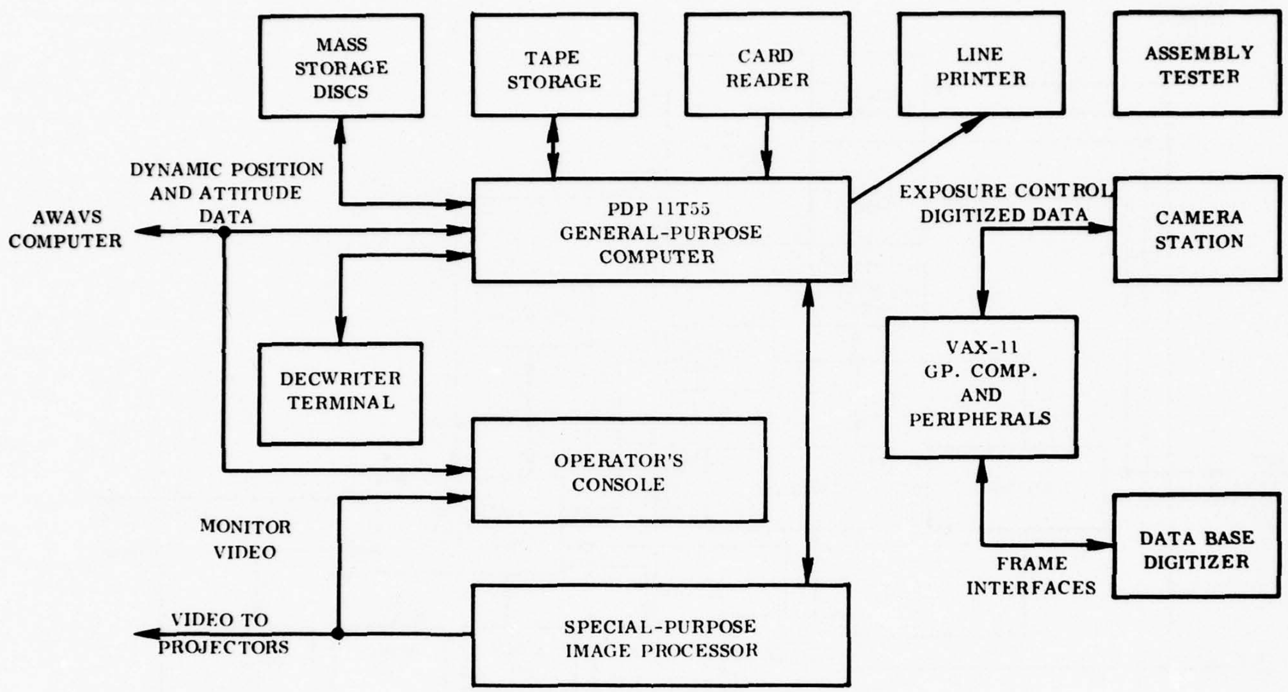


Figure 1. AWAVS CIG System Diagram

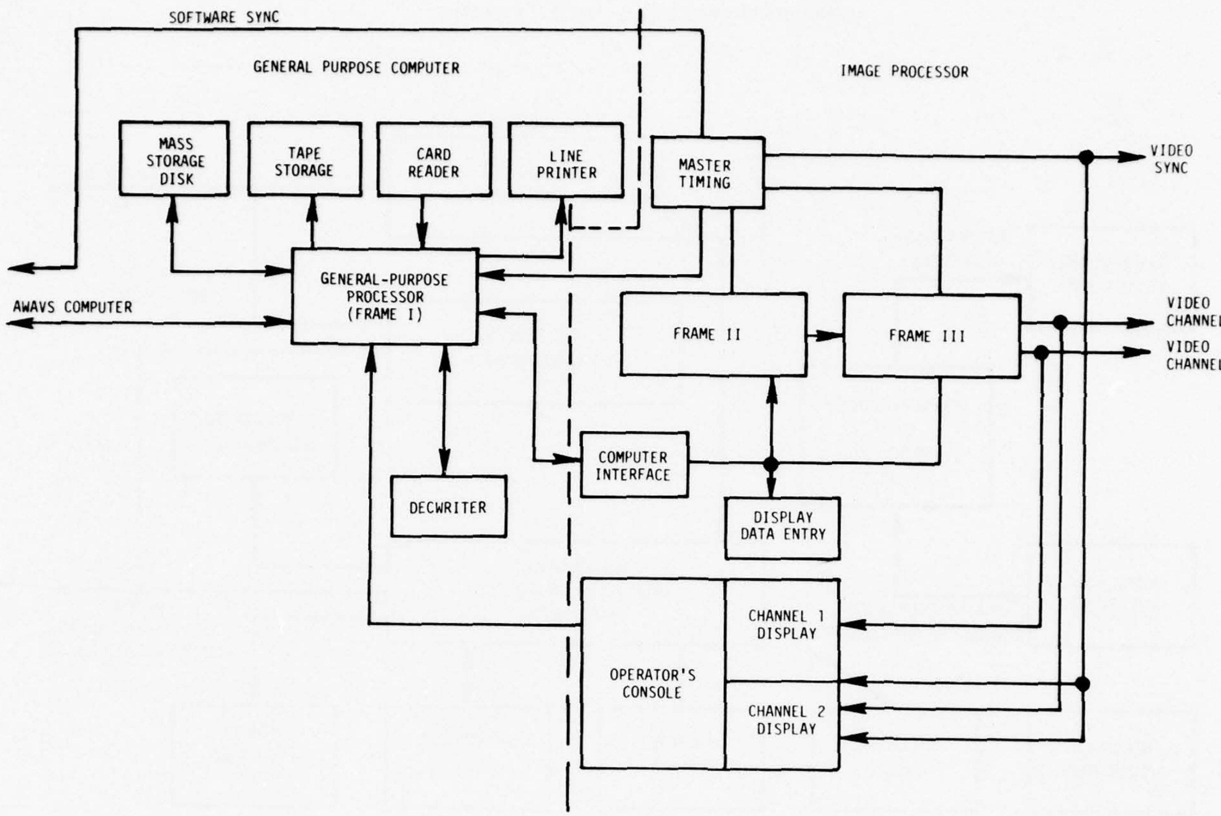


Figure 2. AWAVS On-Line CIG System

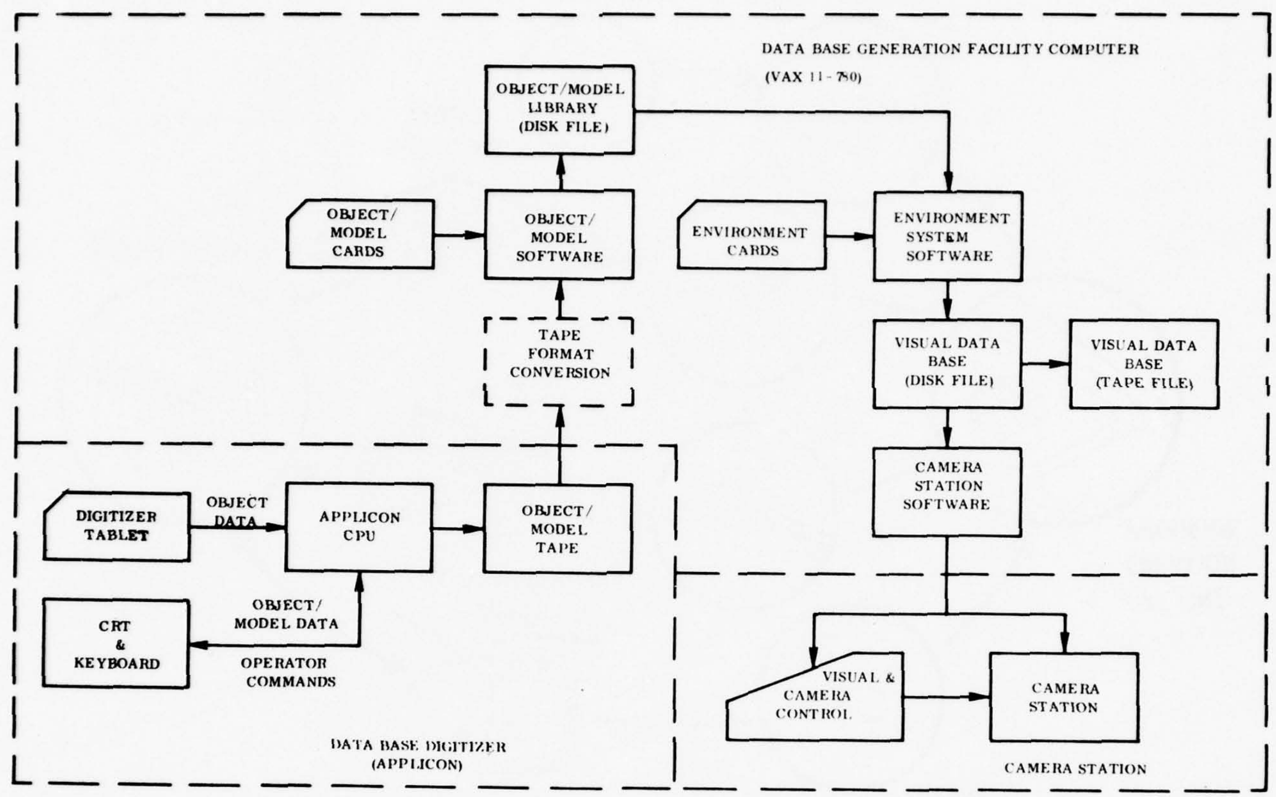


Figure 3. Off-Line Facility and Camera Station

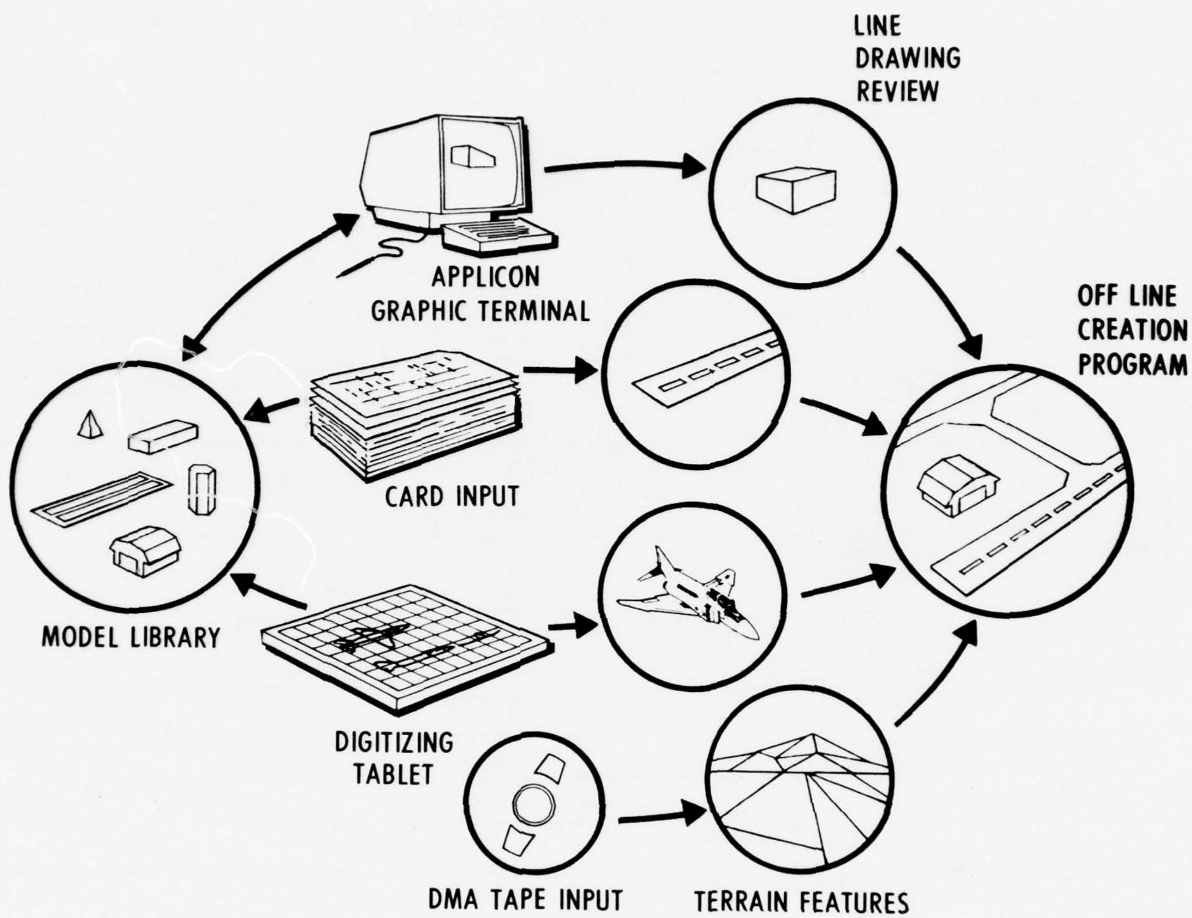


Figure 4. Data Base Creation Functional Diagram

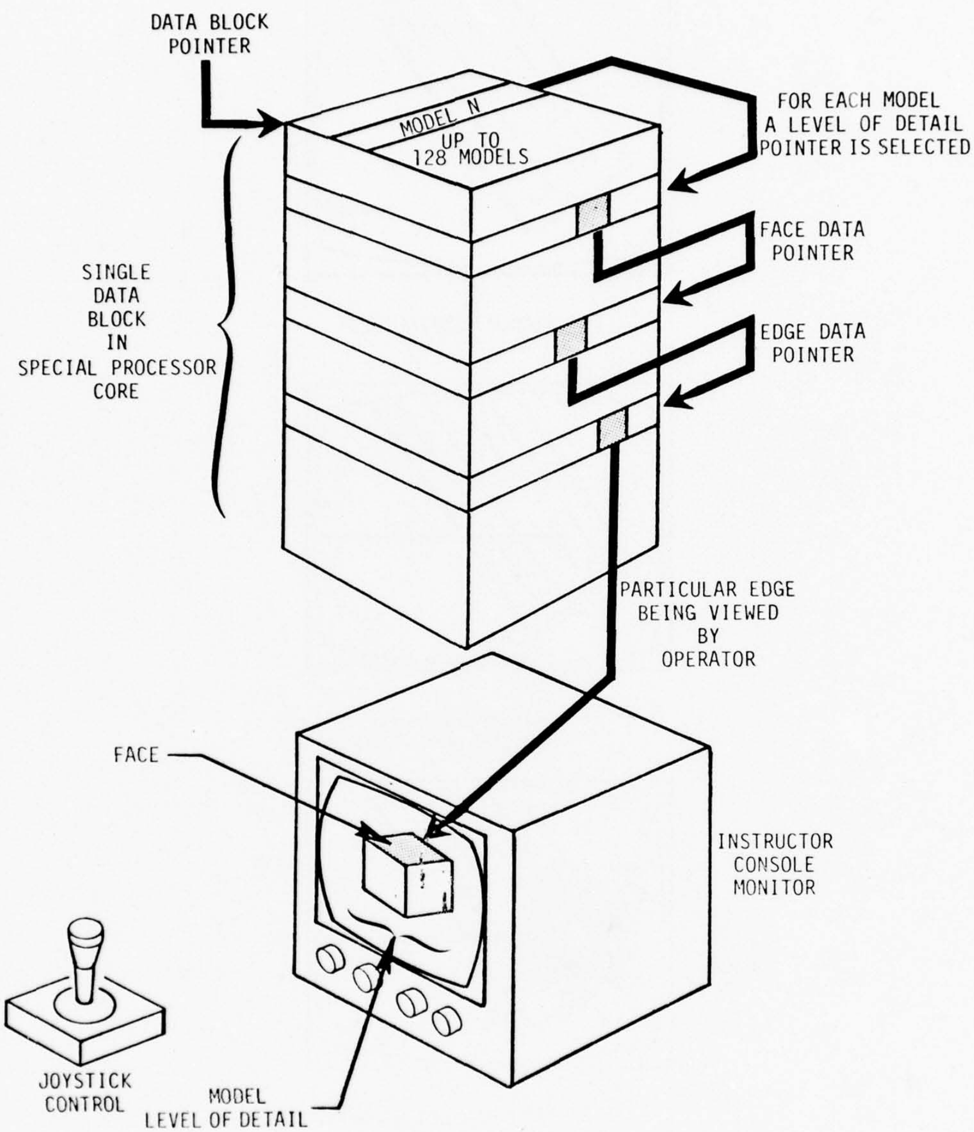
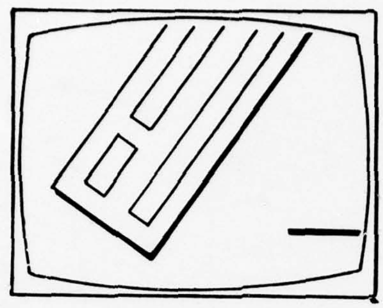
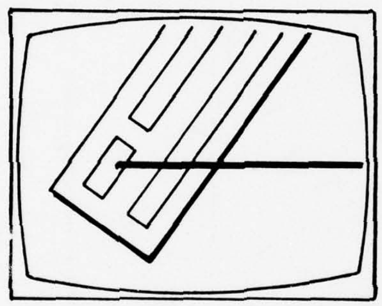


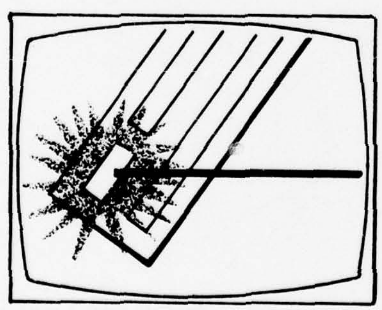
Figure 5. AWAVS Data Block Structure



(a) MARKER INITIALIZED



(b) MARKER MOVED TO "TOUCH" DESIRED FACE



(c) FACE FLASHES ON/OFF PROVIDING CONTACT VERIFICATION

Figure 6. Interactive Marker

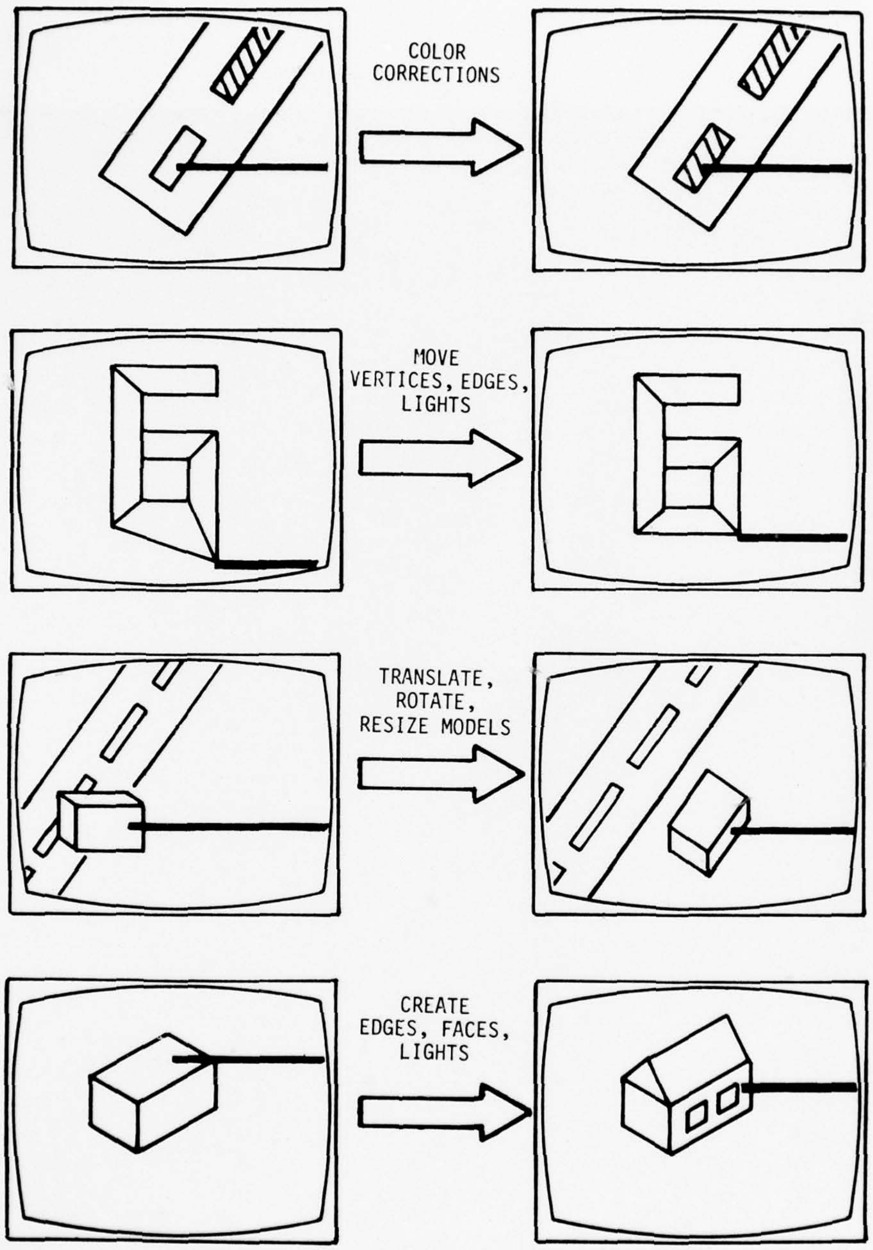


Figure 7. On-Line Interactive Modifications

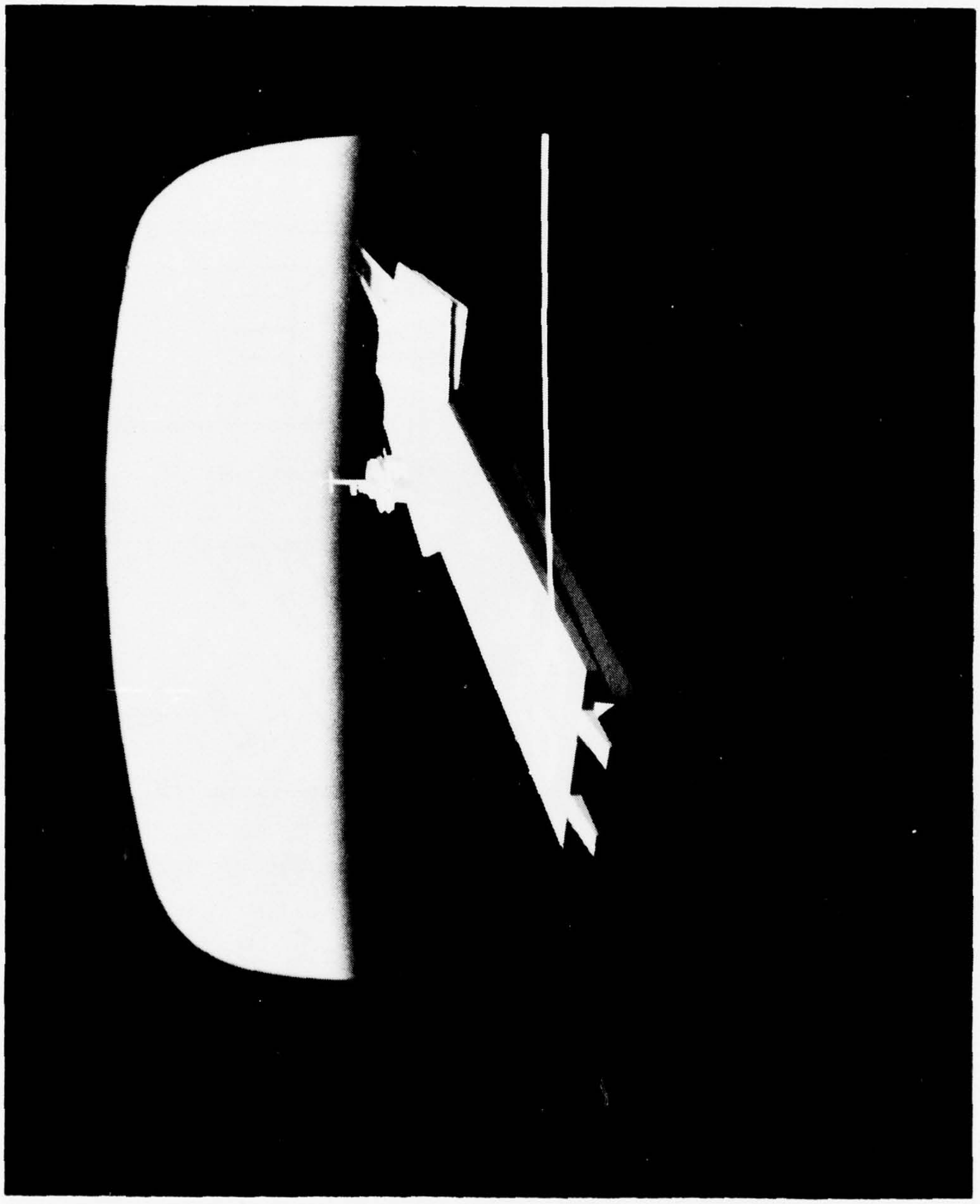


Figure 8. AWAVS Data Base Being Developed — Pointer Activated

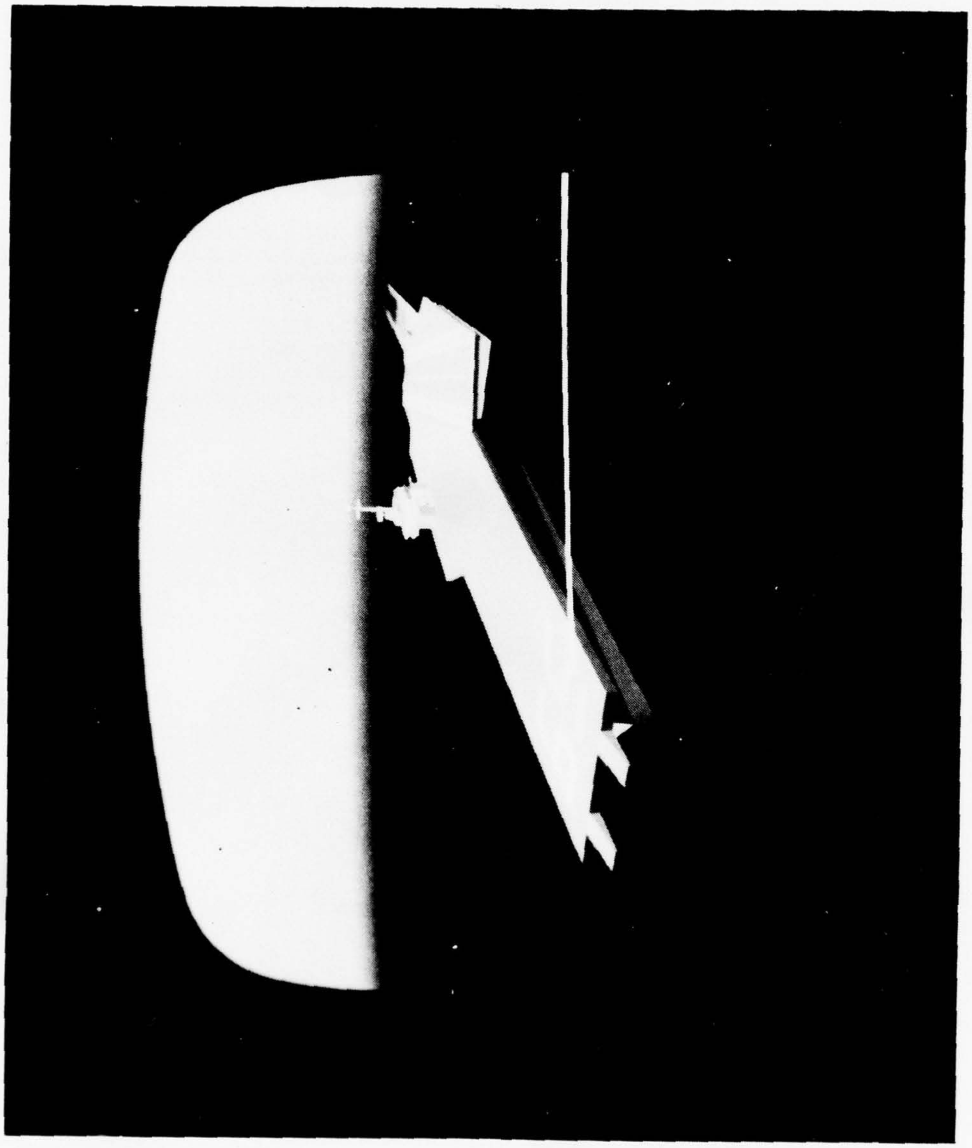


Figure 9. Result of Modification is Immediately Validated

ABOUT THE AUTHORS

MR. JAMES KOTAS is the Senior Computer Image Generator Test Engineer at General Electric. He is presently responsible for all simulation system integration, testing and developing system production test methods. He previously was systems designer of the Aviation Wide-Angle Visual System Computer Image Generator facility and subsequently supervised the development, test, and on-site integration of that system. Prior to this, he led the checkout and installation team for the Navy's 2B35 Computer Image Generator System at Meridian and has been a lead designer in the 2B35, Boeing, and Advanced Simulator Pilot Trainer Visual Simulator Systems. Mr. Kotas received a B.S. degree in electrical engineering at the South Dakota School of Mines and Technology and an M.S.E.E. degree at the University of Florida.

MR. JOHN L. BOOKER is a Project Engineer in Research and Technology at Naval Training Equipment Center, Orlando, Florida. His research includes computer generated displays both in Computer Image Generator and interactive man-computer interface, real-time computer software, and computer systems architecture as applied to training simulators. He has also worked for the Martin Company in the area of logic and computer interface design. Mr. Booker holds an A.B. degree in journalism from the University of North Carolina, a B.S. degree in electrical engineering from North Carolina State University, and the Master of Engineering degree from the University of Florida.

WHEN DAY IS DONE AND SHADOWS FALL, WE MISS THE AIRPORT MOST OF ALL

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ABSTRACT

Both the effectiveness of pilot training and the safety of flight can be influenced by the distribution of texture in the visual scene, the distance to which the eyes accommodate, and the associated shifts in the apparent size and distance of objects in central and peripheral vision. Results to date indicate that these factors are involved in various misjudgments and illusions experienced by pilots: (1) when searching for other airborne traffic or targets, (2) when making approaches to airports over water at night, (3) when breaking out of low clouds on a final approach to a landing by reference to head-up or head-down displays, and (4) when practicing simulated approaches and landings or air-to-surface weapon deliveries by reference to synthetically generated visual systems.

WHAT THIS TALK IS ABOUT

1. Making landing approaches over water on a dark night toward a brightly lighted city.

2. Looking for intruding airplanes from the flight engineer's seat.

3. Sitting inside a screened porch and trying to read a NO FISHING sign down by the lake.

4. Projecting afterimages onto the walls of a football stadium.

5. Watching the moon rise over Miami.

What do these seemingly unrelated activities have in common? And what does all this have to do with head-up flight displays, head-down imaging displays, helmet-mounted displays, and visual systems for contact flight simulators? In each case visual illusions occur: systematic misjudgments of size and distance relationships, departures by varying amounts from the so-called "size-distance invariance hypothesis."

VISUAL ILLUSIONS IN FLIGHT

When pilots make approaches and landings with any type of imaging flight display projected at unity magnification, they tend to come in fast and long, round out high, and touch down hard. On the final approach the runway appears smaller, farther away, and higher in the visual field than it does when viewed directly from the same flight path on a clear day. This finding has been obtained independently both with flight periscopes and with simulated contact visual systems (Roscoe, Hasler, and Dougherty, 1966; Palmer and Cronn, 1975; Roscoe, 1976).

In stark and tragic contrast, when pilots make approaches to landings over water on a dark night toward a brightly lighted city, the runway appears larger, nearer, and lower in the visual field than it does when viewed directly from the same flight path on a clear day. On several occasions in recent years, a commercial airliner has landed in the water short of the airport when making an approach at night. Kraft (1968; 1978) has shown that pilots will systematically misjudge the height and "tilt" of the runway and make low approaches under these conditions.

In another experiment by Kraft, Farrell, and Boucek (1970), a group of pilots judged the threat of midair collision with intruding airplanes at varying distances and angles, none of which represented an actual collision threat. The pilots were presented a series of pictures projected onto a screen viewed from a mocked-up Boeing 737 cab. When the judgments were made from the flight engineer's seat, as opposed to the pilot's seat, the same pilots consistently judged the intruders to be a greater threat at all ranges out to 3500 feet. From the rear seat, the intruders appeared reliably larger and closer than from the front seat.

The viewpoint from the flight engineer's seat is nearly two meters from the windshield aperture; from the pilot's seat it is less

than one meter. Furthermore, the view from the flight engineer's seat includes much of the instrument panel when searching for intruders. When searching head-up from the pilot's seat, the instrument panel appears in the dim periphery; the pilot sees mainly empty space through a windshield that reflects glare and may be dirty or scratched. These conditions suggest that pilots may unknowingly be subject to the "Mandelbaum Effect."

In 1960, Mandelbaum reported an informal experiment in which he asked subjects to read a distant sign from a screen-enclosed porch. For each observer he found a critical distance from the screen at which the sign could not be read, although it was clearly legible from other distances, either nearer or farther. Upon questioning, the subjects realized that they could not help focusing on the screen from the critical distance but could readily focus on the sign by moving either nearer or farther from the screen or by quick movements of the head from side to side. Mandelbaum concluded that the "effect" was due to involuntary accommodation.

It was noted that the critical distance from the screen varied from person to person, with an average distance of about one meter. In an ingenious series of experiments at Pennsylvania State University, Owens (in press) has subsequently determined that the critical distance is the distance of the individual's dark focus, or resting accommodation. For the young, healthy eyeball, that distance on average is slightly less than one meter (slightly more than one diopter in optical terms), the distance of the dirty windshield from the pilot. Almost any textured visual stimulus at that distance is a powerful involuntary "accommodation trap."

A SCIENTIFIC MYSTERY

In addition to the misjudgments of size and distance discussed so far, bias errors in depth discrimination have been discovered independently by designers of submarine periscopes, tank periscopes, laboratory microscopes, "one-power" scopes for shotguns, and helmet-mounted CRT displays. All require some optical magnification to cause objects to appear at the same distances as when viewed by the naked eye. Furthermore, all involve reductions in the field of view and in the textural gradient that serves as the stimulus for distant accommodation. These biased perceptions of size and distance are not fully explained, at least not sufficiently to give comfort to the pilots and passengers of airplanes.

The mystery manifests itself in many forms that have puzzled psychologists from Ptolemy who tried to explain the "moon illusion" to Young (1952) who had subjects project visual afterimages onto the walls of the Ohio State football stadium from various distances across an open field. The farther the afterimage is projected, the larger it appears, but not in direct proportion as would be predicted by the size-distance invariance hypothesis. The "size" of the moon also varies with the extent of the visible textural gradient, appearing larger over a distant horizon than it does over a near horizon, as shown by Kaufman and Rock (1962).

Throughout the literature of vision research may be found additional examples of unexplained experimental findings and assorted "optical illusions" that may be related to the observations by Wheatstone (1852) and Helmholtz (1867/1962), and more recently verified experimentally by Biersdorf and Baird (1966), by Leibowitz, Shiina, and Hennessy (1972), and by Roscoe, Olzak, and Randle (1976), that the apparent size of an object changes with shifts in the distance to which the eye is accommodated. The phenomenon can be illustrated by any one of several simple experiments.

For example: close one eye, focus your open eye on your thumb held at arm's length, observe a more distant object such as a window or a picture on the wall, and while continuing to focus on your thumb, draw it toward you and observe the change in the size of the window or picture. Better yet: look at the moon through a peekhole through your fist, alternately closing and opening the other eye. Not only can the moon on the horizon be made to appear smaller, but also the moon overhead can be made to vary in apparent size by a surprising amount.

INVESTIGATING THE MYSTERY

To investigate the possibility that shifts in apparent size are associated with shifts in visual accommodation distance, an experiment was conducted at NASA's Ames Research Center in which visual accommodation was measured continuously, using a Crane-Cornsweet infrared optometer, while subjects viewed discs that subtended a constant 3° angle at distances ranging from 1/4 to 4 meters, with and without the distance cues provided by a sometimes visible textural gradient (Roscoe, et al., 1976). Shifts from binocular to monocular viewing were accompanied by shifts in accommodation, both inward and outward, toward an intermediate distance of a little less than one meter (1.13 diopters, on average).

The reliable inward shifts from the most distant targets at 4 meters were accompanied by reliable reductions in apparent size. A contingency analysis, summarized in Table 1,

TABLE 1.

SUMMARY OF CONTINGENT PROBABILITY ANALYSIS OF PREDICTED JUDGMENTS OF RELATIVE SIZE WITH CORRESPONDING SHIFTS IN ACCOMMODATION (CHANCE PROBABILITY OF CONTINGENCY = 0.25).

	DISTANCE TO TARGET, METERS			
	1	1-1/2	2	4
CHANCE CONTINGENCY	.25	.25	.25	.25
OBSERVED CONTINGENCY	.23	.36	.38	.45
Chi^2	___	7.59	11.34	25.01
$\underline{p}$	n.r.	<.01	<.002	<.001

showed that the correlation between shifts in apparent size and shifts toward the resting accommodation distances of the individual subjects increased with target distance. At one meter there was a chance relationship, at 1 1/2 meters the contingency was reliable at the $\underline{p}$ <.01 level, at two and four meters the $\underline{p}$ values were < .002 and < .001, respectively. At four meters the contingency was almost 2 to 1 greater than chance, which shows a highly likely relationship but still leaves a lot of variance unaccounted for.

To clarify the relationship between accommodation and apparent size, 12 of the original 16 subjects were tested on near (1/4-meter) and far (4-meter) targets with a 1-mm diameter artificial pupil placed 8 cm from the entrance plane of the eye used for monocular viewing. An artificial pupil allows the eye to lapse farther toward its resting position without causing a blurred image (Hennessy and Leibowitz, 1975). In binocular viewing the second eye was unobstructed, thereby requiring more accurate accommodation to obtain a clear image of the target. The results of this comparison are shown in Table 2.

The arrows in Table 2 indicate the shifts in accommodation toward the resting position from binocular to monocular viewing, and the plus-signs indicate coincidence of positive accommodation shifts and "Monocular Smaller" judgments, or conversely, negative accommodation shifts and "Monocular Larger" judgments. The introduction of the artificial pupil clarifies the relationship: for the 4-meter target, the coincidence is virtually perfect, 23 of 24 cases in agreement; for the 1/4-meter target, accommodation shifted in the predicted direction 9 times in 12 under both light and dark ambient illumination, but only in the dark is there evidence of a trend toward "Monocular Larger"

TABLE 2.

SHIFTS IN MEASURED VISUAL ACCOMMODATION AND JUDGMENTS OF THE RELATIVE SIZE OF THREE-DEGREE DISCS, VIEWED MONOCULARLY (M) AND BINOCULARLY (B) AT DISTANCES OF 25 CM (4.00 DIOPTERS) AND 4 M (0.25 DIOPTER) UNDER NORMAL ROOM LIGHTING (LIGHT) AND REDUCED ILLUMINATION (DARK), WITH AN ARTIFICIAL PUPIL IN FRONT OF THE LEFT (MONOCULAR) EYE.

	Distance to Target Disc							
	25 cm (4.00 diopters)				4 m (0.25 diopter)			
	Dark		Light		Light		Dark	
S	B	M	B	M	M	B	M	B
1	2.64 →	2.07 +	3.07 →	2.27 +	0.69 ←	0.24 +	1.18 ←	0.28 +
2	3.70 →	2.81 +	3.88 →	2.50	1.06 ←	0.32 +	0.12 ←	-0.43
3	3.86 →	2.86 +	4.42 →	1.78 +	0.87 ←	0.26 +	-0.21 ←	-0.78 +
4	0.26 →	0.17	0.49	0.79	-0.15 ←	-0.67 +	-0.58 ←	-0.97 +
5	1.86 →	1.51	2.18 →	1.06	-0.12 ←	-0.61 +	0.17 ←	-0.33 +
6	4.13 →	2.86	4.40 →	3.38	0.07 ←	-0.14 +	0.53 ←	-0.56 +
7	3.04 →	1.76 +	3.75 →	2.14	1.02 ←	0.68 +	0.63 ←	0.39 +
8	4.30 →	2.66 +	4.66 →	4.12 +	0.26 ←	-0.11 +	-0.10 ←	-0.54 +
9	2.18 →	1.83 +	1.71 →	1.07 +	-0.13 ←	-1.02 +	-0.08 ←	-0.84 +
10	3.13 →	1.94 +	3.95 →	3.15 +	0.58 ←	0.06 +	0.22 ←	0.02 +
11	2.58 →	2.24 +	3.12 →	2.51	1.73 ←	0.35 +	1.25 ←	0.45 +
12	3.32 →	1.98 +	3.08 →	1.54 +	0.18 ←	0.05 +	-0.33 ←	-0.41 +
Mean	2.92	2.06	3.23	2.19	0.51	-0.05	0.23	-0.31

Legend: Arrow indicates that shift from binocular to monocular accommodation is toward intermediate distance. + indicates that a positive shift in accommodation is accompanied by a judgment of "Monocular Smaller" or, conversely, a negative shift by "Monocular Larger."

judgments with outward shifts in accommodation (9 of 12 cases, $p < .10$).

In addition to the fact that correlations do not guarantee causal relationships, these findings are equivocal because of the confounding of shifts in accommodation, which were measured, with shifts in convergence between binocular and monocular viewing, which were not measured. Furthermore, the accommodation data are not sufficiently clean for comfort, and a few individual data are suspect by inspection. Nevertheless, neither the data nor their implications can be discounted as completely spurious in the absence of better data. In any case, the mystery is not so much how we judge the size and distance of near objects that afford binocular cues as it is how we judge distant objects that provide only monocular cues.

To gain a better understanding of the effects of visual accommodation upon judgments in tasks involving complex, dynamic visual scenes, another experiment was recently conducted at Ames Research Center using the Crane-Cornsweet infrared optometer and an experimental night-landing visual display generated by a digital computer (Randle, Roscoe, and Petitt, in press). Professional pilots made judgments of whether they would undershoot or overshoot their landing aimpoint as the computer flew their simulated jet transport on final approaches to the computer-generated airport scene.

Experimental variables included: (1) the magnification of the visual scene, which was varied in five steps between 0.83 and 1.67, (2) the visual accommodation distance induced by five sets of ophthalmic lenses with dioptric powers ranging from zero to three, (3) the actual descent path of the simulated airplane, which included overshoots and undershoots as well as correct landing approaches, and finally, (4) whether the landing scene was presented as a real image viewed directly on a TV monitor or a virtual image produced by a collimating field lens mounted between the monitor and the pilot.

The first finding was that the eye does not respond obediently to the accommodation distances called for by ophthalmic lenses; the eye is lazy and reluctant to be drawn away from its intermediate resting position. The brain, in turn, seems happy to accept an amazingly out-of-focus image uncritically and, in fact, without conscious recognition that it is out of focus. In response to ophthalmic lenses covering the range from zero to three diopters, the pilots' eyes, on average, accommodated to the virtual and real images over ranges of only 1.27 and 1.46 D, respectively.

Despite the relatively small shifts in accommodation "induced" by the ophthalmic lenses, there were statistically reliable interactions in the predicted directions between actual accommodation levels and the pilots' judgments of whether they would overshoot or undershoot their landings. There is now little doubt that such judgments are related in some complicated way to visual accommodation distance, which, in turn, is affected far more by the various viewing conditions encountered in the spectrum of normal flight operations than it was by the ophthalmic lenses used.

An experiment typically raises more questions than it answers, and this one was no exception. The pilots made two judgments along the final approach, the first at 20 seconds, or 4000 feet, before passing the runway aimpoint and the second at 10 seconds, or 2000 feet. With unity image magnification, they predominantly indicated an overshoot on the first judgment and an undershoot on the second. If they had been flying manually, they would have tended to overshoot. Veridical judgments were obtained at the nearer distance with an image magnification of 1.25, as has been found with flight periscopes (Roscoe, et al., 1966).

The possible explanations for this curious reversal in judgments are infinite. Of course, the finding might be unique to the particular computer-generated night visual scene used. However, based in Kraft's findings, it could be that pilots habitually make low approaches at night to avoid overshooting and, when they are still 4000 feet out, "expect" the runway to appear as it does from a position below the 3-degree approach path. At 2000 feet out, they can see their position better and maintain thrust to carry them to the touchdown.

At 4000 feet out the dominant cues for accommodation, namely, the airport lighting system and the lighted city beyond, appear as a thin horizontal band of point sources at a relatively great distance; far accommodation is required to resolve the scene. As the airplane approaches the runway, the band deepens and comes nearer; the runway lights are more easily resolved, and accommodation drifts inward from its distant "trap." The so-called "size constancy" of the runway is not maintained; in effect it shrinks a little, and pilots tend to overshoot their aimpoint once they have safely crossed the threshold.

To test this wild speculation, two experiments have just been conducted at the University of Illinois (Iavecchia, 1978). A 1/2-degree collimated disc of light, simulating the moon, was projected onto a 45-degree

combining glass so that it appeared as a virtual image superposed on the outside visual scene (a la Kaufman and Rock). A second, comparison "moon" of adjustable diameter was presented as a real image at a distance of one meter in an otherwise dark surrounding. The two views were presented alternately in the same visual position by means of a sliding mirror arrangement, and the subject adjusted the diameter of the comparison until a satisfactory apparent-size match was obtained.

In the first experiment, conducted in clear daylight, subjects viewed the collimated moon against the scene visible from corresponding windows of the third to the eighth floors of the Psychology Building overlooking the Urbana campus and residential area. On the third floor the moon was projected against the roof of a nearby sorority house, and on successively higher floors against successively more distant rooftops and large trees. At the fifth and sixth floors it appeared just above the horizon, and on the seventh and eighth, higher and higher above the horizon. The apparent size of the moon increased from the third to the sixth floors and then reversed itself as it rose above the horizon.

The mean apparent size ratios of the moon, relative to its apparent size when projected onto a newspaper viewed from one meter, were (3rd floor) 1.143, (4th) 1.250, (5th) 1.311, (6th) 1.364, (7th) 1.330, (8th) 1.282. These means differed reliably ($p < .05$). As the moon was projected against increasingly distant surfaces from the 3rd through the 6th floors, its apparent size increased monotonically. From the 6th floor, the moon was projected against the sky just above the most distant surface texture. From the 7th and 8th floors, it was projected against the sky higher and higher above the horizon.

In the second experiment the distance and vertical position of visible texture was manipulated more systematically by viewing the scene from the fifth floor through a series of masks. Four of the masks revealed horizontal bands of texture in the Near, Intermediate, Far, and Very Far visual fields. Another mask obscured all surface texture in the visual field so that the moon was projected against the open sky just above the "horizon" formed by the mask. Finally, a clear mask revealed the entire scene. The results of these tests clarify the situation.

When viewing the moon against the "unmasked" background scene (clear-mask control condition), its apparent size ratio was 1.369. With the mask that revealed only Near texture, it was 1.225; for Intermediate texture, 1.235; for Far texture, 1.289; and for Very Far texture, 1.395. With the mask that obscured all surface texture below the horizon (similar to a view of the moon overhead), the apparent size ratio dropped abruptly to 1.136, only slightly larger than its apparent size when projected onto the newspaper viewed from a distance of one meter.

What these two experiments show is that the apparent size of objects well beyond the 6-meter, or 20-foot, distance to "optical infinity" change reliably with changes in the spatial distribution of textural stimuli to accommodation in the background visual scene. The greater the distance through empty space to resolvable texture, the larger the apparent size of centrally fixated objects, such as the moon or an airport runway. As the textural pattern extends downward or moves nearer, the central object fails to maintain a constant "apparent size." As the pilot approaches a runway over water at night, his visual image of the runway grows, but not in perfectly inverse proportion to distance remaining.

When no resolvable background texture is present, as when viewing the moon against a clear sky, the textureless moon provides an inadequate stimulus to distant accommodation and shrinks in size, as do the symbols of a head-up display when flying in clouds. Even a partially clouded sky apparently cannot hold distant accommodation to a textureless collimated moon or display symbols. Thus, the "moon illusion" is not manifested by a spuriously large moon on the horizon but rather by a perceptually shrunken moon overhead.

IMPLICATIONS FOR FLIGHT SAFETY

For years Kraft, Hennessy, and several other investigators have recommended that pilots routinely wear bifocal lenses at night and when making IFR approaches in daylight conditions. The lower section would optimize their vision for instrument panel and chart viewing distances. The upper section would provide negative correction to aid distant accommodation for outside viewing. Owens and Leibowitz (1976) have shown that, if night drivers with normal vision are asked to select the lenses that allow them to see best, they will choose those with a negative correction halfway between their dark focus and optical infinity.

To combat the possible underaccommodation experienced by some pilots while making "black hole" approaches over water at night, lead-in light buoys should be considered and tested for use at major airports. Although no specific data are available, it would be expected that, in the absence of visible texture in the near field, pilots with extremely distant dark focus would be the ones who tend to make low approaches at night and occasionally land in the ocean.

Perhaps they should wear positive corrective lenses at night, but evidently no such tests have been made.

The use of head-up displays for night and IFR approaches warrants further investigation. It has been tacitly assumed and strongly asserted by the advocates of such displays that the collimated presentation prepares the eyes to resolve immediately whatever is out there to be seen. Available experimental evidence does not support that assertion. The CIG/NVS landing approach study at Ames (Randle, et al.) and the moon-illusion studies at Illinois (Iavecchia) clearly show that collimating bold, well defined symbology, whether viewed directly or reflected from a combining glass, does not necessarily call the eyes to a far accommodation distance. When the pilot breaks out of the clouds, rapid negative accommodation is required, and the scene "explodes."

IMPLICATIONS FOR PILOT SELECTION AND TRAINING

The evidence presented suggests that dark focus, or resting accommodation distance, in addition to basic visual acuity and color vision, should be taken into account in pilot selection and assignment. Having a far resting accommodation distance might be one basis for assigning military pilots to air combat duty; they should be less troubled by empty-field myopia. Those with a nearer resting position might benefit from negative lenses, as in the case of civilian pilots watching for intruders. As pilots get older their resting accommodation may retreat into the distance, occasionally to a point at which they could have serious problems making "black hole" approaches.

There is ample empirical evidence that pilots learn to compensate for the biased distance judgments they experience at night and with flight periscopes and the visual systems used in flight simulators. Specific training in the relationships between viewing conditions and the direction and magnitude of the associated visual biases would expedite learning the appropriate compensations. Providing variable magnification in computer-generated night visual systems as a function of the variations in visibility and illumination simulated would give the manufacturer another training feature to sell--one that might be worth its cost.

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PILOT JUDGMENT: TRAINING AND EVALUATION

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JUDGMENT — perhaps the key to longevity in naval aviation. Judgment is obviously critical in the inflight regime where multiple decisions must be made in a timely, correct, and often irreversible fashion. Just as important, and perhaps too often overlooked, is the importance of good judgment on the ground. Knowing when not to fly, planning flights carefully, and realizing personal limitations are examples of good judgment displayed on the ground (Dunn, 1977).

INTRODUCTION

From the beginning of aviation history pilots have been expected to exercise a considerable amount of judgment in the overall task of flying an airplane. However, in recent years, increasing demands in our society for safety, dependability, economy, effectiveness, and reduced energy consumption have increased the complexity of civil and military flying operations magnifying the pressures for good pilot judgment. Furthermore, technological advances that have eased much of the pilot's burden for precise aircraft control have not greatly eased the pilot's decision-making workload. In many cases these advances have only created demands for higher levels of skill, knowledge, and judgment to which few pilots have been trained, and the training costs to prepare them to operate effectively in the changing system are becoming prohibitive.

Flying has developed so rapidly that there has been little time for a serious study of what flying is all about, particularly in terms of how pilots think. Many changes in regulations are expedients designed to solve problems that have already developed. Often solutions to existing problems create new ones, which in turn, are "solved" by new regulations. The problem of training new pilots and retraining current pilots to facilitate the implementation of new procedures and regulations in a mobile but energy limited society is just beginning to be recognized (Roscoe, 1974).

However, if it were merely a matter of teaching flying skills, the training of pilots to operate safely in our complex aviation system would be a much smaller one than it is. Unfortunately, because actual conditions are never quite the same as those used to develop aviation regulations, procedures, and performance limitations, the safety of a given flight also depends upon a significant amount of evaluation and interpretation of existing conditions by the pilot.

For example, the conditions used to develop flight performance values for a particular type of airplane may be ideal including clean airplane surfaces, a new engine, a new propeller, an unrestricted air filter, and a company test pilot. In actual conditions the pilot must compare these book values obtained in ideal conditions with those in which he finds himself. These actual conditions may include a dirty airplane, a slightly used engine, a few marks on the propeller, a slightly dirty air filter, and a less than perfect pilot. He must then evaluate many other conditions such as gross weight, center of gravity, wind, temperature, humidity, altitude, etc. for comparison with those used in the book to determine his expected flight performance. Finally, he must check the present and forecast weather, the terrain, and expected traffic density and compare them with an estimate of his own capability before determining whether or not his planned flight will be safe.

Examples such as these requiring decisions with less than perfect information are available in all areas of flight activity. Furthermore, every decision that the pilot makes is colored by physiological, psychological, and social pressures that are virtually impossible to weigh properly on the spot. For example, just as persons watching a sporting event may "see" an infraction or foul differently depending upon their vantage points and which team they support, a pilot may be influenced to view the weather outlook or his own abilities differently depending on the importance or value he assigns to a given flight. The person's self-image and his need to maintain his external image largely determine how much effect different values or rewards for making a flight will have on his judgment of his ability to make a safe flight (Kogan and Wallach, 1964).

Mental weaknesses in some pilots may cause them to be susceptible to social pressures that result in less than rational pilot judgment. Such irrational pilot judgment is characterized by such unsafe practices as flying under bridges, landing on busy

highways, attempting to land in football stadiums, and flying "formation" on other unsuspecting pilots. Potential sources of social pressure that may lead to these types of activities include peer reactions, fear of failure, censure from superiors or family members, and many others (Janis and Mann, 1977).

Although it may be a difficult task (Fishbein and Ajzen, 1975), pilots must be tested, not only for their knowledge, skill, and rational judgment capabilities, but also for their irrational judgment tendencies as these apply to safe flying. It is apparent from accident statistics that new approaches to pilot training and testing are needed to improve the safety and effectiveness of civil and military pilots.

Training and Testing Effectiveness

An assessment of the effectiveness of current pilot training and testing programs should start with a categorical analysis of training objectives associated with the end product: a pilot licensed to fly under a certain set of regulations. Civilian training objectives may be classified under three sets of behavioral activities as follows:

Procedural Activities

- Communication management
- Navigation management
- Fuel management
- Powerplant management
- Vehicle configuration management
- Display management
- Autopilot management

Perceptual-Motor Activities

- Vehicle control
- Distance, speed, altitude, and clearance judgments
- Hazard detection and avoidance
- Communication
- Geographic orientation

Decisional Activities

- Pilot self-evaluation of skill, knowledge, physical, and psychological condition
- Navigation planning
- Hazard assessment
- Assessment of attention requirements
- Assessment of aircraft and ground system capabilities
- Mission priority adjustment

A useful next step in the examination of the effectiveness of current pilot training and testing programs that may help to identify weaknesses is to analyze general aviation accident data in which pilots were "found to be a contributing cause or factor." Statistics from the National Transportation Safety Board (NTSB) Automated Aircraft Accident and Incident Information System from 1970 through 1974 were used in this analysis (Jensen and Benel, 1977). Pilot cause/factors from the NTSB data were classified into the three behavioral categories given above. Then the total numbers of both fatal and non-fatal accidents during the five-year period were determined for each of these behavioral categories. The results of these analyses are shown in Table 1.

Table 1. Number and percent of the total general aviation accidents in which the pilot is listed as a cause or factor between 1970 and 1974.

	FATAL	NON-FATAL
Procedural	264 (4.6%)	2230 (8.6%)
Perceptual-Motor	2496 (43.8%)	14561 (56.3%)
Decisional	2940 (51.6%)	9087 (35.1%)

Although these satistics of pilot-caused accidents reflect the influence of more factors than just pilot training deficiencies alone, examinations of these data provide valuable indications of possible weaknesses in current programs. For example, a majority of the non-fatal pilot-caused accidents (56.3 percent) were the result of faulty perceptual-motor behavior. The most significant factors here (failure to maintain flying speed and misjudgment of distance, speed, altitude, or clearance) represent one type of pilot judgment. On the other hand, a majority of the fatal pilot-caused accidents (51.6 percent) were the result of faulty decisional behavior, another type of pilot judgment. The most significant factors in this area were the familiar "continued VFR into known adverse weather" and "inadequate preflight planning or preparation."

It is apparent from these accident statistics that both aspects of the deciding function are important to safe flight and possibly suffer from neglect in the present training and testing process. However, because it suffers from greater misunderstanding in aviation circles, pilot judgment as represented by the general decisional activities is the topic of concern in this paper. Although a significant amount of research has been done on this aspect of judgment in recent years (Janis and Mann, 1977) no one has specifically examined this judgment problem faced by the pilot, the flight instructor, and the pilot examiner.

There appear to be three major problems that require solution before major improvements to pilot training and evaluation

can be realized in this area. The first is the establishment of a common definition of judgment as it applies to flying. At present, even though the term is used repeatedly in aviation circles and FAA examiners are required to evaluate candidates on the basis of judgment, no such definition exists.

The second major problem is to determine whether or not pilot judgment can be taught, and if so, how can one best teach it. Because some aspects of pilot judgment are closely akin to personality characteristics, they may be difficult to modify. It may be necessary to use testing and selection procedures to improve aviation safety and effectiveness from these standpoints. Other aspects of pilot judgment are more easily modified through systematic training procedures.

The third major problem is to determine whether or not pilot judgment can be evaluated reliably, meaningfully, and objectively. Because judgment is primarily a mental process, it may be difficult to evaluate in any reliable way. On the other hand, behavioral events frequently have been used to infer mental activity. Although personality tests have proved to be somewhat unreliable, research results using these instruments may be useful in the development of instruments for evaluating and predicting judgmental behavior (Fishbein and Ajzen, 1975).

<u>Judgment Definition</u>

As indicated above, the word judgment has been used to describe two somewhat different mental processes in aviation. Perhaps its most common usage has been to describe the mental activity that takes place at the perceptual-motor level. The second describes the mental activity involved in choosing a course of action from among several alternatives. Obviously, this second usage of the term is similar to the first in that both involve making choices.

However, there is a basic difference. The first refers to highly learned perceptual responses that must be made in a very short time, in some cases continuously. The second, refers to cognitive decisions for which set procedures have not been established or may have been forgotten. Flight instructors have used various terms referring to this type of judgment including "headwork," "thinking ahead," and "staying ahead of the aircraft." Usually, more time is available to evaluate the situation, a larger number of possible courses of action must be considered, and there is a greater degree of uncertainty concerning the existing situation and possible outcomes than is the case in perceptual judgments. For these reasons, cognitive judgments have been the source of greater misunderstanding in pilot training and evaluation.

These two aspects of judgment may be considered as two ends of a continuum based on cognitive complexity and decision time. One such representation is shown in Figure 1. At one end of the continuum, are the common *perceptual judgments* of distance, altitude, speed, and clearance. These perceptual judgments are less complex in that they involve fewer pieces (frequently one) of fairly accurate information from which responses are determined with highly learned motor behavior. They may require simple responses but frequently call for immediate control movement.

At the other end are what might be called cognitive judgments. As described above, these judgments are very complex in that they usually involve a large number of relevant pieces of highly probabilistic information, they usually require the specification of and choice from among several alternatives, and they are frequently affected by emotions, values, and social pressures. In addition, cognitive judgments usually permit some deliberation before a control response is required. The remainder of this paper is concerned with this aspect of pilot judgment.

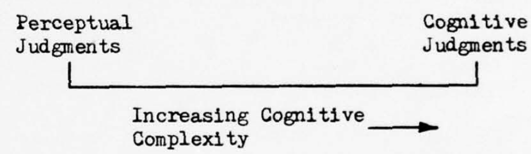

Figure 1. Judgment Continuum Based on Cognitive Complexity and Decision Time

<u>Cognitive Judgment Definition.</u> Considering these factors a candidate definition of cognitive judgment in flying airplanes is:

1. The ability to search for and establish the relevance of all available information regarding a situation, to specify alternative courses of action, and to determine expected outcomes from each alternative.

2. The motivation to choose and authoritatively execute a suitable course of action within the time frame permitted by the situation.

Where:

1. "Suitable" is an alternative consistent with societal norms.

2. "Action" includes no action, some action, or action to seek more information.

The first part of the definition refers to intellectual abilities. It depends upon human capabilities to sense, store, retrieve, and integrate information. This function is what Van Dam (in Jensen and Benel, 1977) calls the "discriminating ability" in professional pilots. In signal detection theory it is called detectability (d'). It is purely rational and could be stated mathematically. If it were possible to separate this part of human judgment from the second part (which it is not), the mind would solve problems in much the same way as a computer. This is not to say that it would be error free. It uses probabilistic information and is dependent upon the amount, type, and accuracy of information stored as well as inherent and learned capabilities to process information.

The second part of the definition refers to motivational tendencies. The emphasis is on the directional aspects of motivation rather than the aspects of motivation dealing with intensity. It says that a part of human judgment is based upon bias factors (costs and payoffs) or tendencies to use less than rational information (defined by society) in choosing courses of action. Society would probably consider the use of any information other than that required to define the safety risk (e.g., monetary gain, gain in self-esteem, adventure seeking, etc.) as less than rational. This part of human judgment is called the response bias (B) in signal detection theory. It is what Van Dam (in Jensen and Benel, 1977) has called the "response pattern" of the professional pilot. If properly developed, this part of human judgment would tend to halt the use of information not directly related to the safety of the flight and to direct the pilot's decision toward the use of rational processes.

JUDGMENT TRAINING

Can Pilot Judgment Be Taught?

The first question to be addressed following the establishment of the definition is whether or not pilot judgment, as defined, can be modified through training. The paucity of judgment training guidelines in pilot training and training research literature leads one to doubt that judgment can be taught. Literature and syllabi commonly used in flight instructor courses contain large sections on how to teach the motor skills of flying but very little on how to teach pilot judgment (see the FAA's Aviation Instructor's Handbook, 1977). The typical private pilot course offers a scattering of judgmental instruction in the areas of weather avoidance and power-plant emergencies but no systematic judgmental training.

However, there is evidence in aviation showing that at least one form of judgmental training, assigning procedures for every conceivable situation that might arise, may be effective. In the military these are referred to as "Boldface" training procedures. Demonstrations by American Airlines (Gibson, 1969) and by Trans World Airlines (Trans World Airlines, 1969) offer convincing support for the conclusion that complex simulators are effective both for the training and testing of pilots using these procedures.

Looking outside the field of aviation one finds other evidence indicating that judgment may be taught. For example, although the theory of signal detection (TSD) was not designed specifically to handle cognitive judgments, many of its methods can be used to explain and perhaps even modify pilot judgment behavior. TSD divides an individual's decision behavior into two components representing his sensitivity (d') and his response criterion or bias (B), roughly corresponding to the two aspects of our judgment definition.

The sensitivity is affected both by the physical value of the stimuli in the situation (signal vs background noise) and the quality of the sensory apparatus of the observer. In cognitive judgment this is the intellective component. On the other hand, the response criterion represents the point in the signal-to-noise distribution at which the observer is willing to say "signal." It is the amount of information, in the presence of noise, needed to tip the decision one way or the other. It is influenced by motivation, knowledge of the signal's probability of occurrence, and the costs and payoffs attendant with a given response. In cognitive judgment the response criterion is the motivative component.

The response criterion can be manipulated through a wide range of values by adjusting probabilities, costs, and payoffs (Birdsall, 1955). We can infer from the vast amount of psychophysical decision data that cognitive judgments can be modified in a similar way. Decision biases, attitudes, risk tendencies, consideration for passenger safety, and pilot motivation can and are being taught by the flight instructor by example, if not by design, at all levels of pilot training. These tendencies are taught, perhaps unconsciously, by the assignment of probabilities, costs, and payoffs to actions of the student by the instructor.

Although TSD says that the sensitivity component is quite stable for a given individual, there is a growing field of research indicating that, if considered as the intellective component of cognitive judgment, sensitivity can be modified as well. For example, attempts have been made to discover the mental processes that are used by expert

judges such as stock brokers, livestock judges, and medical diagnosticians in making their decisions (Shanteau and Phelps, 1977; Slovic, 1969; Anderson, 1969; Hoffman, Slovic, and Rorer, 1968). The hypothesis is that if models of the mental processes used by these experts in decision-making were available, they could be used in training others to use similar processes. In each of the areas studied, judgmental training traditionally occurs over a fairly long apprenticeship program in which the trainee observes the expert make decisions and learns by this observation. However, as in aviation, because of the complexity of the information used to make decisions, observation or even trial and error are inefficient training methods.

The research on the motivative aspect of cognitive judgment also indicates that training can have a beneficial effect. The major research efforts in this area are reported by Janis and Mann (1977). These authors, speaking from a clinical perspective, begin with the assumption that psychological stress is a frequent cause of errors in decision making. They say that stress arises from at least two sources. First, the decision-maker is concerned about the material and social losses he may suffer from whichever course of action he chooses, including the costs of failing to live up to prior commitments. Second, he recognizes that his reputation and self-esteem as a competent decision-maker are at stake. The more severe the anticipated losses, the greater the stress.

Janis and Mann have constructed a "conflict-theory" model of decision-making postulating that the way we resolve a difficult choice is determined by the presence or absence of three conditions: "awareness of risks involved," "hope of finding a better solution," and "time available in which to make the decision." They have developed several clinical procedures to improve decision-making under the titles, "awareness-of-rationalizations," "emotional role playing," "balance sheet," and "outcome psychodrama." They report that these procedures have demonstrated effectiveness in changing decision-making tendencies and in attitude modification.

A Systematic Approach to Training

The need for pilot judgmental training has been established for all levels of flight instruction. Without a systematic judgmental training program, good pilot judgment is acquired by the cautious and the lucky over years of flying experience in many varied situations. Our task as aviation educators using systematic judgmental training techniques should be to compress a lifetime of flying experience into a relatively short training program to instill good pilot judgment into the emerging private or military pilot.

The evidence presented in the preceding section indicates that many aspects of pilot judgment can be taught. The questions that remain are: what approaches should be taken to implement pilot judgmental training and what techniques should be used to evaluate the level of judgment possessed by a pilot or flight student. This section presents a systematic approach to pilot training emphasizing judgmental instruction.

Before proceeding, it is necessary to establish some definitions and constraints involved in this approach. First, training and education, which have been distinguished elsewhere (Glaser, 1962), will be considered equivalent and defined as the "systematic acquisition of skills, rules, concepts, or attitudes that results in improved performance in another environment" (Goldstein, 1974). The "systems approach," a term that has been used and abused in many ways, should, in this training context, emphasize the specification of instructional objectives, precisely controlled learning experiences to achieve these objectives, criteria for performance, feedback within the system, and a recognition of the interaction among system components.

In addition to these, the approach to pilot judgmental training should consider the following constraints: the cost and time required of both student and instructor, the qualifications required of the flight instructor and examiner, and the safety requirements to administer such a program. Finally, although a systems approach is used to develop the training context, the major burden of judgmental training falls directly on the flight instructor. He or she is responsible for the creation and use of innovative situational teaching techniques.

An Instructional Model. A model of an instructional system adapted from one developed by Goldstein (1974) is useful for the establishment of the system context for pilot judgmental training. This model shown in Figure 2, presents five basic interrelated phases in a closed-loop instructional system: assessment, selection, development, training, and evaluation. All five phases are needed to accomplish the goals of a systematic approach to any instructional program. The feedback from the evaluation phase to the assessment phase indicates that an instructional system is never complete. It needs continual adjustment based on the results of the evaluation phase and inputs from the environment.

The assessment phase consists of the establishment of the instructional need and a

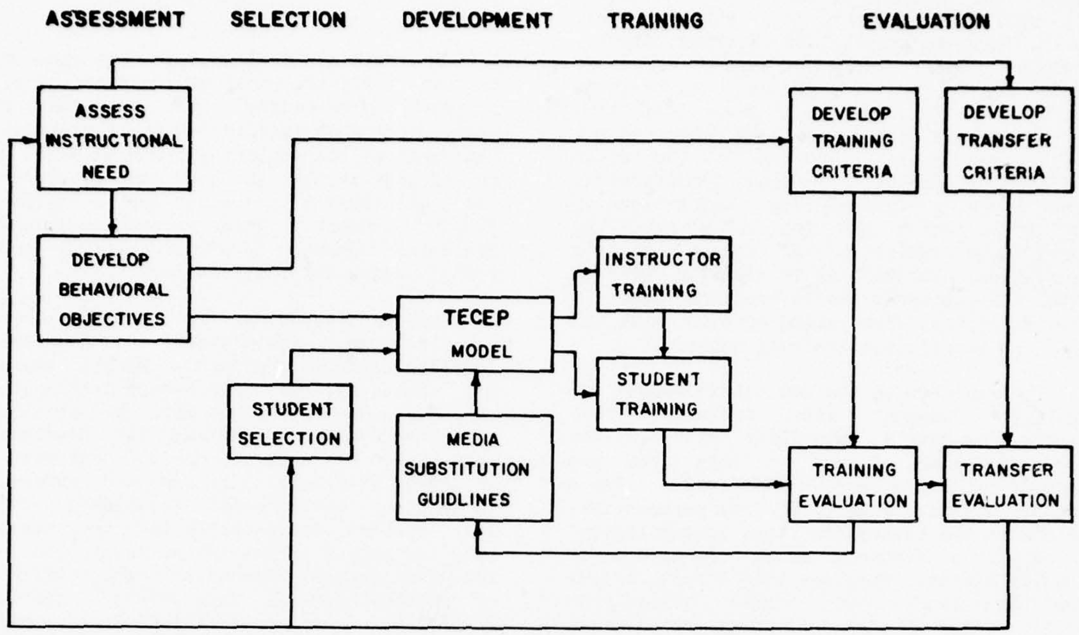

Figure 2. A Model for Pilot Judgmental Training

derivation of behavioral objectives. An assessment of the need for pilot judgmental instruction first requires an anaylsis of the present and future requirements for pilot judgment in the flying environment. Second, this assessment requires an analysis of the judgmental task from the behavioral standpoint. Third, it requires an analysis of human attributes necessary to perform the judgmental tasks. These three analyses provide the basis for the development of judgment behavioral objectives.

Behavioral objectives should specify what the trainee will be able to accomplish when he successfully completes the instructional program. They should also indicate the conditions under which the performance must be maintained and the standards by which the trainee will be evaluated. Thus, they provide direct inputs both into the evaluation phase and the development phase of the instructional model.

The selection phase consists of a program of psychological tests primarily aimed at the identification of persons likely to exhibit irrational judgment behavior during their flying career. For obvious reasons, this phase would be easier to apply in military settings than civilian settings, even though accident statistics have shown that such selection methods might save lives. The necessary instruments for effective application of this phase are yet to be developed.

The development phase consists of the establishment of a training program to achieve the behavioral objectives. The development of this program requires a blend of learning principles and media selection based on the skills, concepts, and attitudes that are to be transferred to the operational flying environment. The learning principles are integrated and matched with appropriate training media in the Training Effectiveness Cost Effectiveness Prediction (TECEP) model (Braby, Michelli, Morris, Okraski, 1972).

The training phase consists of both instructor and student training programs. Because judgmental instruction requires the use of situational teaching techniques, instructors will need special training to administer these techniques. The instructor training program will also serve as the source of much of the situational material used in judgmental training.

The evaluation phase consists of the systematic measurement of changes brought about by the training program. Thus, the evaluation phase requires the establishment of measures of success (criteria), based on the behavioral objectives, and the measurement of judgmental behavior both before and after the

training process. Although rarely seen, data from these evaluations are vital to the success of any training program. As Goldstein (p. 23) points out, "...instructional programs are research efforts that must be massaged and treated until the required results are produced."

In pilot judgmental evaluation there also is a requirement for the assessment of judgmental capabilities and tendencies relative to an absolute standard determined by what society expects of pilots. This evaluation would be included as a part of the pilot certification process. Such an evaluation requires a knowledge of societal demands concerning pilot judgmental capabilities, at least qualitative criteria against which to judge the candidate, and an unbiased observation of performance to determine whether or not the candidate meets the criteria.

Some Learning Principles

Because of the common misapplication of some well established learning principles in many training programs, a discussion of these principles as applied to pilot judgmental training is needed. Perhaps the most popular of these is the assumption that the best way to learn an activity is to practice that activity (Gagne, 1962). This assumption is rooted in much of the educational literature and is often identified by the catch-phrase "learning by doing." Gagne points out that it may also be a generalization of the research on the conditioned response in which learning, particularly in animals, appears to have occurred only after a response (practice) has been made.

However, Gagne argues that practice is not an effective training method by itself, even for the acquisition of such motor skills as field gunnery. He says that "instruction about the correct sighting picture for ranging is more effective in bringing about improved performance" than is practice on the task. The point is that training should emphasize the principles and procedures (thought processes) involved, and practice should be directed to take advantage of these principles or take a minor role. If this is the proper emphasis for teaching motor skills, it is even more important in the teaching of judgmental skills which are more highly rooted in thought processes.

A second learning principle that is frequently misapplied in training situations is variously called reinforcement, feedback, or knowledge of results during practice. This principle has been found to be most effective in choice behavior. However, Gagne points out that some manipulations that artificially improve feedback during practice failed to show reliably better transfer to the operational environment and others showed negative transfer. Apparently the form of the feedback is important.

Any beginning flight student will tell you that the usual feedback information such as "you did it right" or "you did it wrong" is almost useless. The time period between trials and feedback may be long, it is often cluttered with interferring information, and the trials themselves are often so complex that the student may learn very little from such a response by his flight instructor. The student really needs to know why he did it right or wrong. He needs to know what rules he should have followed and where he strayed from those rules. Although practice and right/wrong types of feedback may be useful in some training situations, they should be de-emphasized in favor of these "thought" oriented teaching principles in all types of pilot training, but especially in judgmental training.

Judgmental Training Media

Because of the nature of the subject matter to be taught (i.e., attitudes, principles, and motivations), the primary load of pilot judgmental training must be borne by the flight instructor. Practice and conventional self-teaching techniques (e.g., solo flying in a practice area) are highly inefficient methods for imparting these concepts. The following is a discussion of some suggested judgmental training media and techniques that could be applicable to pilot training in civil and military aviation.

Ground School. There are a number of excellent ways that pilot judgment could be taught from the perspective of the conventional ground school. To afford it proper emphasis, it is suggested that judgment should be given a special section of ground school with the same status as meteorology, navigation, and Federal Air Regulations. This section could include lectures and/or discussions of aviation accident senarios in which the pilot was a cause or factor, interactive movies, video tapes, slide presentations requiring student judgmental responses at critical points in flight senarios, and independent study of the principles involved in good pilot judgment.

In addition, this ground school section could include instruction in information integration and subjective probability estimation (Goldberg, 1968). Judgmental behavior in expert judges is characterized by chunking, or the formation of clusters of stimulus attributes and response alternatives, for economy in the thought process. Ground school students could be taught to use these processes in their judgmental activity. The

instructor would show how various types of probabilistic information such as weather forcasts, predicted aircraft system malfunctions, and predicted Air Traffic Control problems should be combined in making flying decisions.

The instructor would teach the student how to "think ahead" or anticipate decisions that might have to be made later resulting from present choices of action. Such anticipation permits the gathering of relevant information under lower levels of stress, when errors are less frequent than later in the flight when time-to-decide may become a error causing factor. This section of ground school could also include decision-making training using procedures suggested by Janis and Mann (1977) such as "balance sheet" and "emotional role playing."

Computer-Assisted Instruction. An instructional technique that holds unusual promise for pilot judgmental training and evaluation is computer-assisted instruction (CAI). The great advantage of these systems is that they can teach principles and then permit the student to participate in decision processes, a highly effective learning technique (Fishbein and Ajzen, 1975). The disadvantage of these systems in the past has been their limited availability and high cost. However, recent advances in technology are making them available at a relatively low cost (Trollip and Ortony, 1977).

Although CAI programs are available in several forms, the dialogue systems that permit student-computer interaction unrestricted by preset response alternatives (Alpert and Bitzer, 1970), show the greatest potential for application to judgmental instruction. These systems depend upon a set of stored algorithms that are used by the computer to construct a great variety of responses to student questions. In addition, student responses are not limited to exact duplicates of prestored expected responses. The program recognizes a variety of student responses and is able to proceed accordingly.

Although practice and feedback are frequently used concepts in CAI programs, these could be augmented by presenting principles and reasons for taking certain courses of action. In judgmental training the student could be presented with a flight situation requiring judgment. He could then be asked to respond by listing all of his alternatives and the factors affecting each. He could even be asked to estimate the probability of success for each alternative.

The computer could then examine the flight experience data on the student (entered previously) and the stored accident statistics from similar circumstances. The computer would then respond with comments on the appropriateness of the student's responses, the alternatives that may have been omitted, and the principles that should have been followed in making the decision. The program could then branch to another problem, the difficulty of which would be based on the level of judgmental capability evidenced by the student's responses to the previous problem.

Complexity, realism, and time constraints could be included in the judgmental task by the addition of a simple flight hand-controller and an airplane symbol with a map on the screen. The purpose of this controller would be to provide indications of progress toward a destination and time available for the decision, not for instruction in flight control.

CAI has many advantages not commonly associated with other instructional systems. The most important of these is individualization of instruction. It can adapt to the specific needs of the individual and interact at his current level of ability (Goldstein, 1974). Second, the unencumbered reinforcement capabilities of CAI are a real benefit to the student. It has no personality or ulterior motives to clash with those of the student. Third, CAI systems do not require the presence of a teacher, although it may be beneficial to have one present for occasional consultation. Fourth, they permit standardization of instruction across a wide area. One central computer could potentially support terminals at every pilot instructional center in the United States at a relatively low cost. No student would be handicapped by a bad instructor who underscores weaknesses in the simulation. Fifth, data gathered from student responses could be stored for as long as necessary for use in updating instructional programs or in evaluating individual pilot judgmental capabilities.

CAI also has a number of limitations that may impact judgmental training. First, very little is known about the effectiveness of the instructional techniques described above. Research is still needed to determine how to program such an instructional system most effectively. Second, large outlays of money would be required for hardware to implement such a program. Third, some users might object to the requirement for communication with the computer via a keyboard, although keyboards are rapidly becoming a part of the pilot's way of life. Fourth, Goldstein (1974) expresses concern for the effects of a machine-oriented learning environment on satisfaction, motivation, and development.

Flight Simulation. Of the various alternatives available for pilot training, it is apparent that, for many operators, flight

simulators may be the most viable for all types of pilot training. The education of pilots for military and airline applications has become increasingly dependent upon ground-based aircraft simulators.

In some ways judgmental training in a simulator environment would be more cumbersome than in ground school or CAI because, at least in current practice, it depends upon the instructor to create the simulated flight situation primarily through verbal communication. Nevertheless, the simulated flight environment provides an additional opportunity to teach judgmental principles, if properly structured, in a somewhat more realistic environment than ground school or CAI can provide.

Probably the best way to begin judgmental training in the simulator is to use the airline approach i.e., teaching procedures that are to be followed in each situation that departs from normal flight. This includes system failure detection as well as establishing courses of action to correct or counter system failures. Principles involved as well as corrective procedures would be taught according to this method, and appropriate judgmental performance measures could be developed.

The simulator instruction could also include the creation, by the flight instructor, of judgment-demanding situations that do not involve the failure of systems. These situations would demand decisions such as whether or not to continue a flight into deteriorating weather, decisions about passenger demands for landing at an unfamiliar alternate airport, decisions about weight and balance considering field conditions, density altitude, etc. In all cases the instructor would ask the student to state several alternatives available to him and also to state which he would choose. These situations could be developed from NTSB accident briefs, and they could be a part of the flight instructor's simulator judgmental instruction package.

Simulator judgmental instruction should be treated as a serious and vital part of the flight student's training. The simulator must be treated as an important training aid just as the airplane and the blackboard are treated. The instructor has the opportunity and responsibility to instill serious, mature flight attitudes in his students by his approach to judgmental training. The simulator provides an outstanding medium for teaching a student good judgment. But the training will only be as valuable as the instructor's approach to simulator instruction is serious.

The Airplane. Of all the media available, the airplane is probably the most difficult to use for direct, systematic judgmental training. The reason is that for the sake of safety, convenience, and cost most judgmental problems must be halted before the student sees the final consequences of his decisions. He frequently must take the instructor at his word that his decision would have resulted in a safe or unsafe situation. However, the airplane offers special opportunities for judgmental instruction because the environment is more realistic, it is more meaningful, and therefore, it is more likely to cause a more permanent behavioral change in the student than other training media.

Everything that has been said about instructor attitudes and approaches to judgmental training applies doubly when actually flying the airplane. Effective judgmental instruction in the airplane requires a consistent, disciplined flight instructor who always follows the rules that the student is expected to follow, or provides a good explanation for why he deviates from them. It also requires that the instructor follow the learning principles stated earlier i.e., that practice and feedback are beneficial only when accompanied by direction and explanations.

Judgmental instructions in the airplane should take the form of simulated situations created by the instructor requiring the use of judgment. Such activities should be interspersed throughout the flight training program. Such instruction is already being done to some extent through training in simulated engine failures, other system failures, and all types of stalls. This training could be expanded to include many of the hypothetical situations discussed above. Portions of such simulated situations could be a part of every instructional flight.

It is the flight instructor's responsibility to teach the student that it is not socially demeaning to refuse to fly or to turn around in the face of deteriorating circumstances. Such situations should be made to occur several times during the student's instruction program in the airplane. Pilots have often said that it is most difficult to turn around the first time. In this regard, it is important to teach the student how to avoid the tremendous social pressure that a group of important passengers can exert. The pilot must be taught to isolate himself from his flight naive passengers in all important decisions.

Finally, often one of the most difficult evaluations a pilot has to make is the self-evaluation of his own skill, knowledge, and judgmental capability relative to a

proposed flight. To assist himself in this regard he should develop a list of personal limitations on flight procedures based on his own capabilities. These limitations must be applicable to all flights regardless of who the passengers are or how much they are willing to pay him to make the flight. They should be invoked during a rational moment, and the pilot's resolution should be strong enough to withstand the enormous social pressure to deviate from them either before or during a given flight.

Situational Emergency Training

The Air Force has begun a research program (Thorpe, Martin, Edwards, and Eddows, 1976) aimed at improving pilot decisional processes during emergency situations. Although the goals of this program are more limited than those of judgmental training described above for civil aviation, the approaches suggested are very similar. The proposed training program being studied, called "Situational Emergency Training" (SET), is designed for the F-15 to replace the traditional "Boldface" procedures of other USAF weapons systems. Although Boldface procedures are effective in many situations where their solutions are applicable, the investigators suggest that there are situations in which these solutions may not apply and such training methods inhibit good judgment in these situations.

SET encourages the development of judgment and centers training around three emergency rules: (a) maintain aircraft control, (b) analyze the situation and take proper action, and (c) land as soon as practical. The underlying concept of SET is situational training. The pilot is taught to discriminate between relevant and irrelevant dimensions of situations which are systematically manipulated in the training program. As pointed out above, this discrimination process is fundamental to good judgment. The authors suggest a scenario development program using instructor training courses as one of the major sources of input.

JUDGMENT EVALUATION

Perhaps the most difficult part of any study of human judgment is the evaluation of performance. The reason is that much of what must be evaluated cannot be observed directly but must be inferred from observation of other related behaviors. From discussions with flight instructors and pilot examining personnel, it is clear that judgment is not being evaluated effectively today (Jensen and Benel, 1977).

Although flight test guides published by the FAA specify that civilian pilots are to be evaluated for their "judgment" capabilities, no definition of judgment is provided. For this evaluation, examiners primarily depend upon the judgment of flight instructors who have the opportunity to examine their student's decision-making capability over a greater variety of circumstances. However, in interviews with flight instructors, only one was found who admitted to having failed a student purely on the basis of poor judgment. Although many said that they could recognize poor judgment, students were failed on the basis of a borderline performance of some other more clearly defined flying maneuver involving skilled performance.

Some ideas for judgment evaluation are offered by Van Dam (in Jensen and Benel, 1977). In his approach, the evaluation begins with psychological and intellegence testing prior to admitting students for flight instruction. Initial impressions from these pretraining examinations are augmented with other subjective indicators of judgment such as "obvious effort and attention to instruction," "relaxation," "division of attention," "response delays," "confidence," "capacity for problen-solving," and "initiative." In later pilot training, evidence of judgment development is seen through an "eagerness to learn or high motivation," "teachability," "adaptability and flexibility," "an intuitive quality in thinking or decision-making," "a pattern of good choices," and "application of margins and allowances."

As indicated in the training system model shown in Figure 2, a vital part of any educational system is an effective evaluation program. Training must be continuously modified in response to the results of these evaluations and progress of the individual students is noted.

The requirements of pilot judgmental evaluation are even broader than these. Society expects pilots to make decisions based on the interests of passengers and property owners. Therefore, judgment must also be evaluated in an absolute sense against this poorly defined scale.

There are three major dimensions along which judgment should be evaluated; each presents a unique problem to the evaluator:

1. The assessment of judgmental capabilities and tendencies prior to flight training.

2. The assessment of the effects of training on pilot judgment.

3. The assessment of the amount of training transferred to the operational flying environment.

Pretraining Evaluation

It is important from the standpoints of both safety and economics to identify persons, prior to flight instruction, who may have difficulty with some aspects of flying judgment. If such individuals could be identified, they could either be discouraged from seeking flight training or their training programs could be modified to offset this deficiency.

Unfortunately, on the basis of psychological testing research to date, the predicted success of such a pretraining evaluation program is not very good. For example, psychologists and others have made many attempts, with little success, to identify a general personality trait known as risk-taking and to link this trait to accident proneness (Shealy, 1974). However, Shealy found that if one were to limit the scope of the test to specific situations, such as down-hill skiing, its predictive validity would be greatly increased. Therefore, it would seem that efforts to develop pretraining pilot judgment prediction tests should not be discouraged by the limited success of the general tests. Instead, efforts should be made to design an aviation specific test with with judgment predictive validity.

Pretraining evaluations of judgment ability in pilot training candidates is a potentially useful adjunct to the entire training and evaluation process. Results from such tests could be used by training management to adapt their programs to emphasize training in areas identified as potentially weak in these tests. Flight instructors could be alerted to possible weaknesses in individual students and adapt their training accordingly.

Tests which could identify risk-taking tendencies (Kogan and Wallach, 1964; Taylor and Dunnette, 1974) and tests which indentify accident proneness (Shaw and Sichel, 1971) are potentially useful in this regard. Situation specific tests, as mentioned above, would be useful in this application and for test development for use in later training as well.

Training Evaluation

The second major dimension along which pilot judgment must be evaluated is an assessment of the amount of change in the pilot's judgment performance that is the result of training. This measure provides an indication of the value of the training program as well as indications of individual student progress.

The development of clearly defined judgmental evaluation criteria presents the greatest challenge to effective evaluation of pilot judgment in all phases of pilot training. To insure that evaluations are made along the same dimensions as the training conducted, the development of these criteria should be based on pre-established behavioral objectives. Judgmental criteria should consist of positive statements of acceptable pilot judgmental behavior for each major area of flight activity. Similar criteria could be developed for every major maneuver taught. These could be graded by the instructor together with evaluations of knowledge and skill each time the maneuvers are attempted.

In pilot training, for each level of pilot experience, certain judgmental hurdles (proficiency levels) could be objectively specified. The instructor, or examiner who evaluates the judgments, would have a range of acceptable performances, also objectively specified. Evaluation of pilot judgment would be a matter of comparing performance against the established criteria in carefully structured situations.

The critical point for judgmental evaluation in a national system is the use of the same criteria by all judges as well as by the pilots themselves. One way to insure standardization of judgmental evaluations is to use a nationwide CAI system to administer tests at specific times during each student's training program. Results of such tests could be used to modify the individual student's training or the training program as a whole.

Transfer Evaluation

The final dimension along which pilot judgment must be evaluated is an assessment of the amount of training that is transferred to the operational flying environment. This means that students who have received special judgmental training are compared with those who have not received such training after both groups have moved into the operational flying environment. The results of this evaluation are used to modify both student selection criteria (or pretraining examinations) and program need assessments.

The criteria for this evaluation are basically the same as those used in training evaluations except that they are more highly influenced by societal demands. Measures of judgmental training transferred can be made in terms of the number of accidents or incidents due to faulty pilot judgment reported within the respective groups.

Operationalizing Judgmental Evaluations

The definition of pilot judgment has two components: discrimination among situational dimensions and response selection. Both components must be evaluated. To operationalize these components for use in any specific

training or testing situation, the evaluator may ask the following questions:

1. For discriminative judgment: Did the student consider all of the alternatives available to him? Did he consider all of the relevant information and assign proper weights to each item? Did he integrate the relevant information efficiently before making his choice?

2. For response selection tendencies: Did the student exhibit any tendency to consider factors other than safety (such as his own self-esteem, adventure, or social pressure) in making his response selection? Did he seem to be highly prone to use semi-relevant factors, such as financial gain or convenience, in situations where safety should have been the primary consideration?

The use of such criteria as these requires more of the evaluator than just an occasional passing glance at the instrument panel. It requires the careful structuring of the situation, perhaps hypothetically, and a careful examination of actions taken by the student. It probably would require a dialogue between the student and the evaluator to establish what the student actually considered in making his choice. Each evaluation must be considered a training device as well, and as such, feedback should be given to the student concerning all aspects of the decision situation known to the evaluator. It is recognized that evaluations of this sort place high demands on the flight instructor. Nevertheless, they seem to be warranted in view of the high number of fatalities caused by faulty judgment, a factor that is hardly being evaluated at all under the present system.

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MULTISENSORY PERCEPTION MODEL FOR APPLICATION
TO AIRCRAFT SIMULATION

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INTRODUCTION

Whether in an aircraft or flight simulator, pilots use information from a variety of sensory mechanisms to determine their estimate of orientation and motion. An understanding of this process and a quantitative model are essential for development of effective simulator motion cueing devices. A multisensory model for dynamic spatial orientation is being developed for this purpose and will be used by the Air Force as a data base for development of current and future force simulation devices. The model is a potential tool for objectively gauging the relative fidelity of different simulation strategies and the relative importance of different cueing devices under various conditions.

Aircraft or simulator motion is translated into stimuli which are processed by dynamic models of the appropriate sensors (visual, vestibular, tactile, and proprioceptive), and are then fed to a central estimator which has been modeled as a linear optimal estimator, specifically a steady state Kalman Filter. In addition to the linear estimation process, some nonlinear effects, such as the well documented delay in onset of visually induced motion, require nonlinear additions to the model. We have attempted to keep such additions to a minimum so as to retain the uniqueness and conceptual appeal of a linear optimization algorithm.

The model has been implemented as a computer program and has predicted some of the important qualitative characteristics of human dynamic spatial orientation under combined wide field visual motion and platform motion. Several types of special tactile and proprioceptive cues are also being considered but have not been validated.

The modeling effort has underscored the need for additional data in some areas and several experiments have been suggested to help fill these gaps.

SENSORS INCLUDED IN THE MULTISENSORY MODEL

The vestibular sensors, located in the labyrinthine structure behind the auditory portion of each ear, are the most thoroughly studied and well defined of the sensory systems under consideration. The semicircular canals are the rotation sensing component of the vestibular system and respond to angular acceleration as would a heavily damped torsion pendulum with some additional rate sensitivity and adaptation.[1 2 3 4] For modeling purposes, the two sets of canals have been replaced by a single cyclopian set at the center of the head and are modeled as shown in Figures 1 and 2.

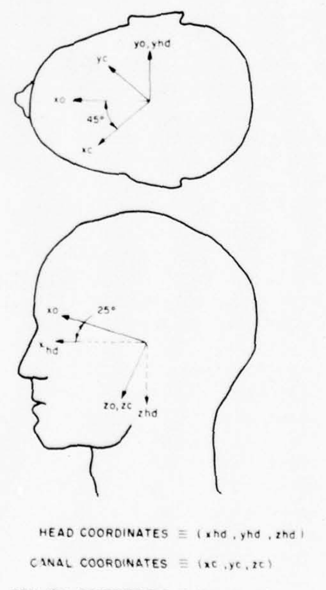

Figure 1. Cyclopian Sensor Coordinates

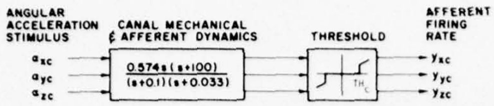

Figure 2. Semicircular Canal Model

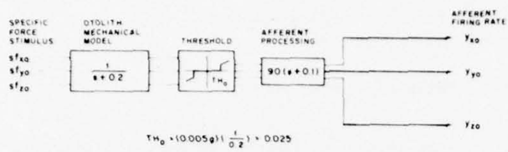

Figure 3. Otolith Model

The otoliths, which form the other component of the vestibular system, sense gravito-inertial force much like accelerometers. As shown in Figure 3, they are modeled as mechanical accelerometers with some additional rate sensitivity presumably due to afferent processing.[5 6] Once again, a cyclopian system has been used for modeling purposes and is assumed to be located at the center of the head. (See Figure 1).

It has long been observed that moving visual fields can induce a sensation of motion such as that sometimes experienced when a neighboring train in a railway station begins to pull away. It has been shown that visual self-motion sensation is proportional to the velocity of the background peripheral vision field up to a saturation level and that the effectiveness of the stimulus is related to the spatial frequency, contrast and resolution of elements in the field.[7 8 9 10] The current model considers only out-the-window peripheral view fields such as moving clouds or star patterns, and specifically excludes cockpit instrument readings or structures such as recognizable landmarks or an horizon reference.

Although movement in the peripheral visual field may not immediately cause a sensation of self-motion, the field motion is detected almost immediately by the eye after only a short neural transmission delay. Dynamics of the visual sensors have, therefore, been modeled as unity, and dynamics associated with onset of the self-motion sensation are ascribed to higher centers.

Tactile and proprioceptive contributions to motion perception are not nearly as well defined as are the visual and vestibular elements. Figure 4 shows a simple tactile receptor model proposed as an initial attempt to consider "seat-of-the-pants" sensation during aircraft or simulator flight. The model uses a single "lead-lag" transfer function to represent the major characteristics of three distinct mechanoreceptors: rapidly adapting Pacinian corpuscles usually found in subcutaneous tissue, and more slowly adapting type I and type II cutaneous receptors.[11 12 13] Several such tactile model elements are used to consider forces applied to various areas of the body.

Although proprioceptive sensation involves numerous muscle length, muscle tension, and joint position receptors, the initial multisensory model considers only muscle spindle (length sensor) response to lateral gravito-inertial force on the head-neck system. The head-neck system, which may be thought of as an inverted pendulum that is balanced on the body trunk with the aid of neck muscles, provides a very important spatial orientation cue and, among applicable proprioceptive mechanisms, lends itself to the most straight-forward modeling. Figure 5, adapted from Gum[14], represents an initial attempt to include proprioception in the multisensory model and will probably be refined and expanded as more experimental data becomes available.

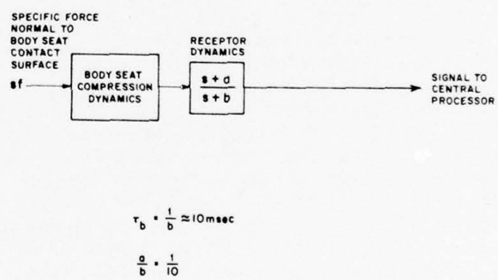

Figure 4. Tactile Model

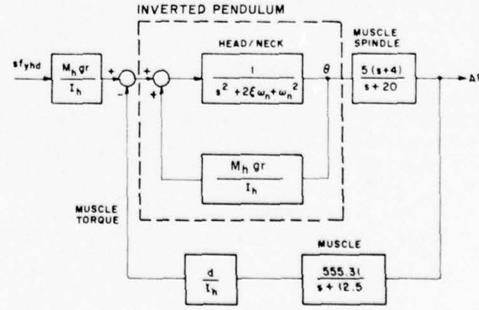

Figure 5. Head-Neck Proprioception Model (after Gum[14])

CENTRAL PROCESSOR

The central processor, representing central nervous system function, is modeled as an optimal estimator which weights each information channel according to certain a priori assumptions. To assign optimal weights, the processor must have knowledge of the sensor dynamics, the expected stimulus spectrum, and the noise in each sensor measurement. This set of assumptions is referred to as the Internal Model since it represents the system's knowledge about itself. If these assumptions include linearity, stationarity, and white Gaussian noise processes, the optimal linear estimator reduces to the well known steady state Kalman Filter and weights or "Kalman gains" can be chosen to minimize rms error of the estimate. Although the biological system is certainly far more complex, our approach has been to start with relatively straight-forward Kalman Filter blending and increase the model complexity only as it proves necessary.

Figure 6 shows a schematic view of the multi-sensory model employing a linear filter alone as central processor. After optimal gains are set, deterministic stimuli corresponding to aircraft or simulator motion are processed by individual sensor models (which may include nonlinearities) and fed to the steady state Kalman Filter. The filter, in turn, estimates state variables corresponding to perception of inertial state and spatial orientation.

Since the proper or logical values for some Internal Model parameters such as the input and measurement noise spectra are

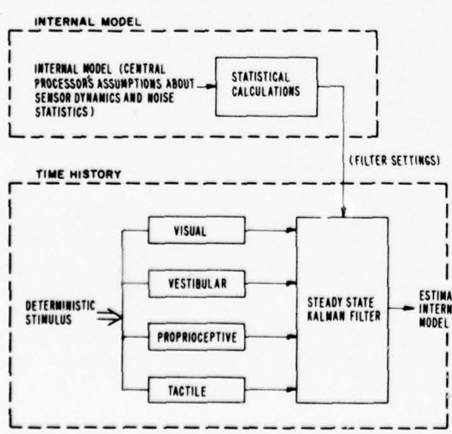

Figure 6. Multisensory Model Using Steady State Kalman Filter To Represent Neural Central Processing

essentially unknown, there is considerable leeway for adjusting model response within the framework described. These unknown parameters have been "tuned" to bring model responses closer and closer to known human response, and we feel that further tuning will result in additional improvement. The initial model represents a naive subject who has no advance knowledge of the stimulus to be received or of the limits of his vehicle. The active pilot with varying skill levels and operating under different workloads is considered to be an extension of the more basic naive case. Possible means for extending the model to the active pilot are discussed later on.

MODEL TIME RESPONSE

The model described in the previous section has been implemented on a computer using the linear estimator alone. Figure 7 shows several responses to combined visual field and platform rotation about the yaw axis. When no visual information is present (in dense fog or in the dark, etc.), the model angular velocity estimate (curve labeled RD) shows the well documented adaptation to continuous rotation which proved to be such a problem for pre-instrument era pilots. It is also significant that the decay in angular velocity perception lags behind that of the semicircular canal afferent response since this relation has also been observed experimentally.

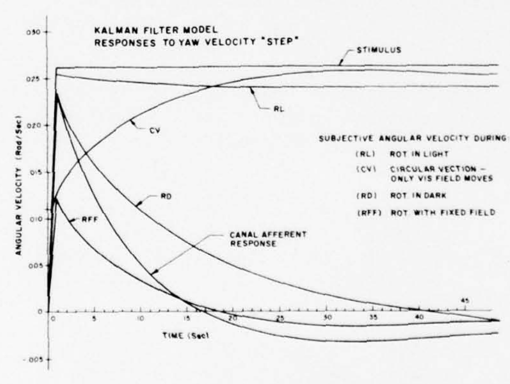

Figure 7.
Model Response To Combined Platform and Wide Visual Field Yaw Motion

When wide visual field information is present and is consistent with a physically stable visual surround, angular velocity perception is a fairly accurate reflection of true angular velocity as shown by the curve labeled RL. When the visual surround is fixed to the rotating platform so that the visual system always reports zero

velocity, the curve labeled RFF shows an adapting response similar to the case of rotation in the dark (RD), but with a smaller magnitude and faster adaptation constant. The RFF curve makes intuitive sense since the visual surround is actively "denying" the presence of motion, not just failing to provide information. In most cases, however, experimental observations have not provided enough evidence to clearly distinguish between the dark (RD) and vehicle fixed-field (RFF) situations, and in some cases RFF appears to be the stronger response, especially for very low accelerations.

When the platform is stationary and the visual surround rotates as, for instance, in a fixed-base simulator with a wide field visual display, the curve labeled CV shows a gradual onset of angular velocity sensation over a period of about ten seconds. This is a classical circularvection (visually induced rotation) response with one qualification. The exponential onset of sensation is shown to begin immediately after the onset of visual field motion whereas a delay is often observed in human response. The onset delay appears to be a highly variable and nonlinear phenomenon which cannot be produced by the steady state Kalman Filter alone and requires the addition of a nonlinear model element as described in the next section.

Except for the absence of a circularvection onset delay, the relations between the various curves of Figure 7 are quite similar to those observed experimentally. Exercise of the Kalman Filter model during pitch and roll plane motion has also produced several important response characteristics observed in human spatial orientation during combined platform and visual field motion. Among these predictions are the following:

1. Gradual illusion of pitch up during prolonged or very large forward acceleration such as commonly experienced by aircraft carrier pilots during catapult launch.[15]

2. Fairly accurate perception of forward acceleration in the presence of confirming visual cues.

3. Fairly accurate perception of roll and pitch orientation changes so long as all cues are consistent (i.e., no translatory accelerations or contradictory visual stimuli).

4. Gradual acceptance of visual field translatory velocity (linearvection) when there is no platform motion.[9]

5. Static tilt illusion accompanying circularvection about a horizontal axis.[16]

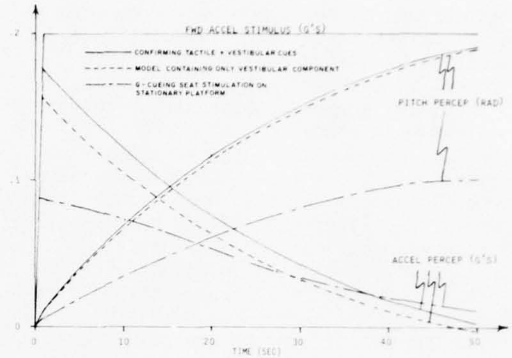

Figure 8. Model Responses to Forward Acceleration Stimuli showing Characteristic Pitch-Up Illusion

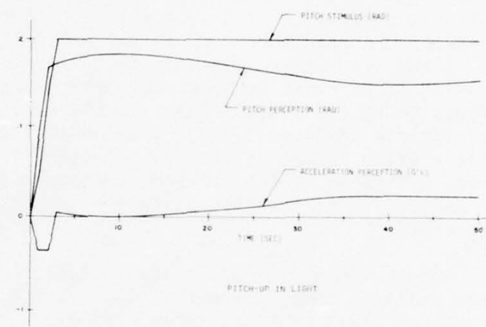

Figure 9. Model Response to a Pitch-Up Stimulus with Confirming Visual Cues. Since the model does not consider specific structure in the visual surround such as an horizon reference, vision provides only pitch velocity and not static pitch angle information.

Preliminary exercise of tactile and proprioceptive model components has yielded responses which appear to be quite reasonable (Figure 8 contains an example of combined vestibular-tactile response), but truly meaningful evaluation of these components requires supportive psychophysical data as yet unavailable.

Quantitative characteristics of the model responses can be further adjusted by additional "tuning" of the linear filter. For example, the RD curve shown in Figure 7 (yaw velocity perception in the dark)

probably lags too far behind the canal afferent response curve and should cross zero ten or fifteen seconds earlier. Some of the responses described are also accompanied by secondary responses which need to be explored further. For instance, the pitch-up sensation of Figure 9 is shown to be accompanied by a relatively small but unexpected translatory motion sensation.

Notwithstanding the need for further tuning, the linear estimator alone is in significant agreement with a wide range of known human response characteristics. Additions to the central processor model, although representing a slight retreat from the conceptual appeal of a pure optimal estimator, can be used to produce some of the nonlinear human responses that the Kalman Filter alone is incapable of generating.

NONLINEAR ADDITIONS TO THE MODEL

Onset of visually induced motion sensation has been observed to occur only after a highly variable delay which is a function of mental set, compelling nature of the display, and stimulus magnitude. For modeling purposes, both a favorable mental set and a compelling display are assumed. Given these conditions, the onset delay is often undetectable when visual stimulus magnitudes are near vestibular thresholds and becomes larger as the visual stimulus exceeds these values. The onset delay also vanishes in the presence of confirming vestibular cues of sufficient magnitude.

Figure 10 shows a generalized cue conflict scheme adapted for use with the Kalman Filter estimator from a conflict model developed by Zacharias and Young.[17] Visual information is used to estimate expected vestibular response and then compared to actual vestibular response. The resultant error signal is rectified and passed through an adaptation operator so that any sustained

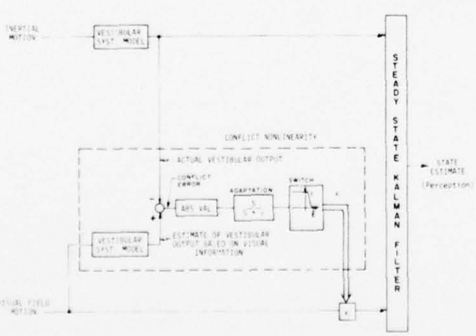

Figure 10. Conflict nonlinearity combined with Kalman Filter Model

errors will eventually be "washed-out." A switch keeps visual gain (K) at unity so long as the rectified, "washed-out" error is small, and gradually drops the gain to zero as this error approaches vestibular threshold value (ε).

Figure 11 shows the response of the combined linear central processor and cue conflict element to a series of steps in visual field yaw velocity, all beginning at t=0. Responses now show an onset delay which increases with stimulus magnitude as found experimentally. The presence of the conflict nonlinearity affects only the circularvection (CV) response in Figure 7. When both the visual and vestibular systems are stimulated (RL curve of Figure 7), the conflict is zero and visual gain (K) remains unity. In the other two stimulus combinations presented in Figure 7, the visual signal is either zero (rotation with a vehicle-fixed visual surround) or nonexistent (rotation in the dark) and K is, therefore, irrelevant.

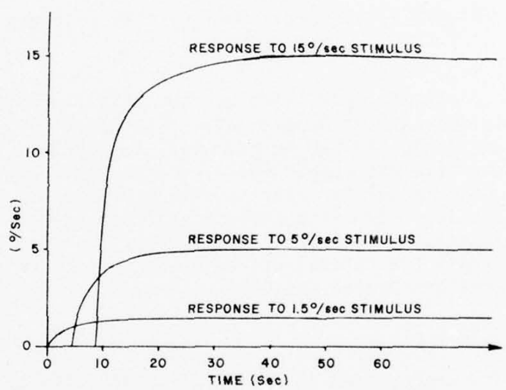

Figure 11. Circularvection step response of model with cue conflict element included. Stimuli are 1.5°/sec, 5°/sec, and 15°/sec steps in visual field yaw velocity beginning at t=0.

Certain illusory effects associated with static orientation in different specific force environments have long been recognized and classified as Aubert, Meüller and Elevator illusion effects. The Aubert effect describes a typical underestimation of tilt angle in a 1g or less than 1g environment; the Meüller effect refers to a characteristic overestimation of tilt angle in a greater than 1g environment; and Elevator illusion is a pitch-up sensation that often accompanies increased g_z. Ormsby[3] has shown that the above effects can be generated by assuming that the

nonlinear function of Figure 12 operates on saccular otolith information ("zo" axis of Figure 1). The multisensory model must incorporate a similar nonlinear element if it is to exhibit Aubert, Meüller, and Elevator illusions.

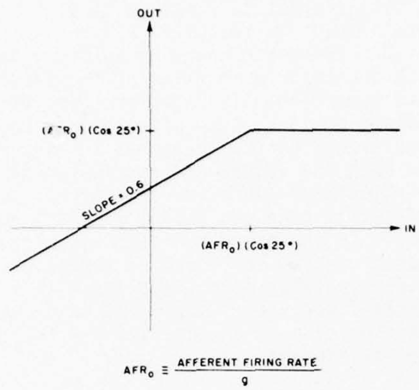

Figure 12. Saccule Nonlinearity (redrawn from Ormsby[3]).

As the model is exercised more thoroughly and as more experimental data becomes available, it may be necessary to further increase the complexity of the central processor model in order to obtain a more precise match with certain observed human responses. Our philosophy, however, is to retain the optimal estimator concept to the greatest degree possible.

ACTIVE PILOT

Perception is dramatically affected by mental set, and prior knowledge or expectancy of motion will certainly influence motion perception. If the multisensory model is to represent an active pilot as opposed to a naive subject, it must be extended to consider the predictive information available to the pilot. Some ideas for such extension are presented in this section.

A skilled pilot may be presumed to have an accurate expectation of input spectra associated with the maneuver being initiated. One modeling approach, therefore, is to assume that the central processor has correct knowledge of the input spectrum for a specific maneuver or portion of a maneuver. The Kalman gains to be used during this maneuver segment can be calculated using that specific spectrum. Since a changing input spectrum does contradict the steady-state assumption, it might be necessary to use a time varying Kalman Filter in place of the steady-state version; preliminary results with the above technique suggests that the steady-state filter may indeed be inadequate. Implementation of a time varying filter is well known and certainly feasible although far more cumbersome in terms of programming complexity and computer time requirements.

A second approach is to incorporate control stick position as an additional input to the Kalman Filter (Figure 13). A skilled pilot knows that a given adjustment of aircraft controls results in a certain change in aircraft state, and thus knowledge of control input becomes data for the central processor. A pilot with less skill might have less confidence in the stick position measure, as reflected in a larger expected measurement noise (v_{stick}), or may rely on a less accurate internal model of aircraft dyna[illegible] the pilot is extremely busy, si[illegible] presumably siphon nervous system attention from sensor motion cue signals, [illegible]ng the system less sensitive to these signals. The decreased sensitivity can be expressed in the Kalman Filter model by increasing the expected sensory measurement noise values.

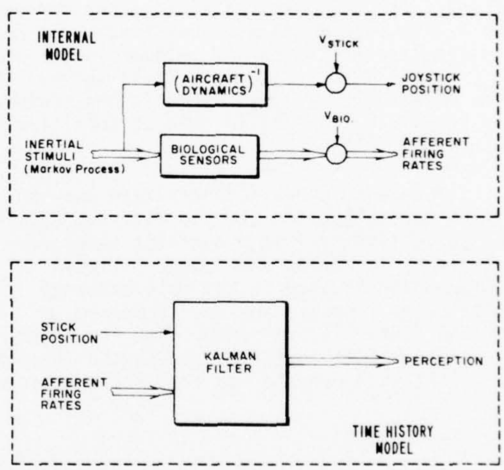

Figure 13. Model Extension to Include Active Pilot

APPLICATION

An effort is currently underway at the Air Force Human Resources Laboratory which is aimed at determining motion cue requirements of fighter aircraft simulators. The multisensory model will be an integral part of this effort with eventual application both to hardware and software development. For example, on a maneuver-by-

maneuver basis, the model can be used to compare perceived motions and forces created by an aircraft with those created by simulator cueing hardware and drive algorithms. Potential simulator deficiencies may thus be spotted prior to extensive subjective testing and sources of existing deficiencies, causing poor pilot performance or complaints that the simulation "doesn't feel right," may be identified. It is anticipated that the model will eventually help to address questions concerning the optimum and most cost-effective combinations of platform motion, visual scene motion, g seat stimulation, etc.

ADDITIONAL DATA REQUIREMENTS

The required data concerning receptor physiology and the results of sensory interaction is by no means complete. Additional data in the following areas would be extremely helpful to modeling efforts:

1. Data needed to help validate or modify the central processor model

...Psychophysical data is needed to determine human perception of several motion cue situations that commonly occur in aircraft but rarely elsewhere. It would be extremely useful to have data concerning orientation and angular velocity perception during coordinated maneuvers (maneuvers in which angular velocity is not accompanied by a confirming change in specific force direction).

...Experiments are needed to clarify the situations under which tactile stimuli are interpreted as motion or orientation cues. In particular, subjective magnitude estimates of acceleration during different combinations of g-cueing seat stimulation and real platform motion would be very helpful. Such data would be directly applicable to g-cueing seat development as well as to the modeling effort.

...In the area of visually induced motion, data is needed to determine the amount of confirming platform motion and/or tactile stimulation required to produce immediate and sustained visually induced motion sensations. In addition to its use for model validation, this data would be directly applicable to specification of platform motion requirements in wide field visual simulators.

...Most motion threshold figures currently available represent optimal detection conditions and may be unrealistic for application to a busy pilot performing demanding tasks in a noisy aircraft or simulator. Experiments are needed to clarify the effect of workload, pilot skill, and masking vibration so that effective thresholds can be properly incorporated in perception models and applied to simulation problems.

2. Data needed to validate or modify individual sensor models

...There is currently very little data available to support the head-neck proprioception model described in this paper. Measurements of dynamic head displacement under lateral and longitudinal gravito-inertial force, as well as electro-physiological measurements of head-neck system response during such stimuli would be a great aid.

...The tactile cue processing model currently employed is based primarily on data generated from neural recordings or vibro-tactile threshold measures in which small area stimuli were applied to the forearm or hand. Threshold and sensitivity to broad area tactile stimulation over the back and buttocks needs to be investigated so that the tactile model component can be improved and expanded.

3. Data to determine the proper stimulus input to the model

...The relation between aircraft motion and body-seat pressure currently is not well known, yet is very important to the modeling effort since it forms the input to the tactile component of the multisensory model. Studies of dynamic body-seat pressure distribution in response to changes in gravito-inertial force, especially during typical aircraft maneuvers, will be a great aid both in modeling and in development of g-cueing seat drive algorithms.

Preparations are currently underway for three experiments that will address some of the needs listed above. It has been proposed that the Air Force Total In-Flight Simulator (TIFS) be used to gather psychophysical motion perception data and to simultaneously study several aspects of the motion cue environment during standardized maneuvers. The maneuvers, which include coordinated turns, "roller-coaster motions," and sustained longitudinal accelerations,

are designed to emphasize stimuli which cannot be adequately represented in existing motion-based simulators. Measurements will be made of perceived direction of vertical and magnitude estimates of roll-rate and translatory acceleration using a special indicator and employing an otherwise passive subject. The dynamics of seat pan and backrest pressure distribution for both the pilot and passive subject will be measured with a set of pressure transducers sewn into or laid over the seats. Video tape recordings of the pilot's and passive subject's head positions with respect to the cockpit will be made for later analysis, and neck muscle activity may also be measured using EMG electrodes. Full documentation of the aircraft's specific forces, angular rates, and Euler angles, will be obtained from an on-board inertial system.

The NASA Manned Carrying Rotation Device (MCRD), because of its capacity for smooth rotation, is ideally suited for study of yaw acceleration threshold and time-to-detect as a function of masking vibration frequency and amplitude. Such an experiment has been planned with Mr. John Stewart and implemented at NASA Ames Research Center.

Dr. David Quam, working with the Air Force Human Resources Lab, is currently preparing to use the Large Amplitude Multimode Aerospace Research System (LAMARS) for a study of subjective yaw velocity under combined platform and visual field motion. This will include determination of minimum confirming platform acceleration and minimum platform excursion needed to produce immediate and sustained acceptance of visual field yaw motion.

CONCLUSION

A multisensory motion perception model has been developed using an optimal estimation approach to the integration of multiple sensory inputs. Although the biological system is far more complex than the linear estimator used in the model, the linear estimator alone has proven capable of exhibiting correct, qualitative human response characteristics to a surprising degree. Some highly nonlinear characteristics such as the well-documented delay in onset of visually induced motion are not produced by the linear central processor but can be generated by adding nonlinear elements to the central processor model.

It is felt that additional improvement and extension of the multisensory model is possible with further development work, including representation of the active pilot; however, additional experimental data in certain areas is badly needed to support such effort. In its eventual application, the model will be useful in objectively predicting motion cue requirements for ground simulation, and developing drive algorithms to produce the highest simulator fidelity under given hardware limitations.

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VISUAL CUE MANIPULATION IN A SIMULATED AIR-TO-SURFACE WEAPONS DELIVERY TASK

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ABSTRACT

Experienced pilots with no prior air-to-surface training practiced a 30 degree dive bombing task in the T-37 cockpit of the Advanced Simulator for Pilot Training (ASPT) located at the Air Force Human Resources Laboratory, Flying Training Division, Williams AFB, Arizona. Use of a bomb impact predictor cue by one group of subjects produced no better performance than that of a second group which practiced without the cue. Abrupt removal of the cue, which during training was not made contingent upon performance, produced a significant disruption of performance on the bombing task, both in terms of accuracy and in terms of variability of performance. Best performance was obtained by a third group for which the gunsight itself was initially withheld in training. The results are discussed in terms of the need in future systems for more active control over the stimuli controlling flying performance as well as the need for research into strategies for making changes in the pilots environment contingent upon performance.

INTRODUCTION

A basic assumption of adaptive training is that a difficult task can be learned more efficiently if it is presented throughout training at a level of difficulty that is matched to the individual's current ability to perform the task. Traditional approaches have sought to control task difficulty through the manipulation of the response characteristics of the task, e.g., Gaines, (1967); Norman, Lowes, and Matheny, (1972).

In some instances, attempts have been made to modify the difficulty of a complex motor skill task by providing augmented feedback to the performer. Lintern (1977) and Lintern and Roscoe (1978), for example, showed that the use of an "off course" augmented cue could be used to enhance the landing training of naive students.

In the present study, an attempt was made to reduce the difficulty of an air-to-surface weapons delivery task in one case through the addition of a visual bomb impact predictor cue and in a second case through selective introduction of a dominant visual cue inherent in the task itself. In neither case, was the introduction or withdrawal of the cue contingent upon changes in student performance. The results of the study are discussed in terms of the need in future sytems for more active operator/instructor control over the visual environment of the learner as well as the need for research dealing with the adaptive use of augmented cuing.

METHOD

Subjects

Twenty-two T-37 Instructor Pilots (IP's) assigned to Williams AFB, Arizona served as subjects. No subject had previous experience with air-to-surface weapons delivery. Their flying experience both in terms of T-37 flying hours as well as overall military flying hours is given in Table 1.

TABLE 1

FLYING EXPERIENCE

	T-37 Hours		Total Hours	
Group	X	s.d.	X	s.d.
Standard	642.00	338.93	1580.32	1185.86
Predictor	701.67	297.21	1150.17	720.93
No Gunsight	922.00	168.88	1158.00	152.30
Overall	721.91	306.86	1367.02	919.50

Instructors for the bombing task were Instructor Pilots assigned to AFHRL's Flying Training Division at Williams AFB.

All were familiar with the air-to-surface task being taught. None were considered, however, as "TAC-qualified" instructors. Because of constraints on the use of instructors, no attempt was made to counterbalance instructors across conditions.

Apparatus

The Advanced Simulator for Pilot Training (ASPT) located at AFHRL/FT was used for training of the air-to-surface task. Technical references for this device are found in Gum, Albery, and Basinger (1975) and in Rust (1975). For the study, the g-seat was inflated but not otherwise operational. Neither was the motion platform in operation. The computer generated visual scene was presented via ASPT's seven 36-inch monochromatic cathode-ray tubes placed around the cockpit giving the pilot +110 degrees to -40 degrees vertical cuing and ± 150 degrees of horizontal cueing. Configuration of the visual scene for this study included a conventional gunnery range visual data base similar to that developed for project 2235 and that used by Gray and Fuller (1977) as well as a depressible bombing sight (A-37 Optical Sight Unit). The aerodynamic mathematical models driving the simulator were those of the T-37 aircraft.

The predictor cue used in the present study consisted of a hexagonal-shaped spot of light, approximately 30 feet (9.114 meters) in diameter, which appeared from the air to move along the ground, giving a continuous indication to the pilot of where a bomb would impact if dropped at that point in time. The manner in which the cue was generated by the system and other details of its implementation are described by Cyrus, Templeton, and McHugh (in press). The cue was programmed so as to be available under command of the console instructor. In the present study, the cue was illuminated continuously. No provision was made by the system to systematically vary the intensity of the cue.

Procedure

Individuals in each of three separate groups (referred to hereafter as Standard Group, Predictor Group, and No-Gunsight Group) of T-37 Instructor Pilots (IPs) performed 15 repetitions of a 30 degree dive bomb task in the T-37 cockpit of the Advanced Simulator for Pilot Training (ASPT). Prior to entering the simulator, each subject completed a short paper and pencil pretraining exercise intended to familiarize the subject with the basic elements of the task. Once the subject entered the simulator, the subject was presented a recorded demonstration of a 30 degree dive bomb task. For the predictor group, the demonstration contained the predictor cue in addition to the gunsight. For the no gunsight group, the demonstration contained neither the gunsight nor the predictor cue. For the standard group, the demonstration contained the gunsight but not the predictor. The narrative content of the demonstration was provided by an instructor pilot seated in the T-37 cockpit beside the subject. Following presentation of the recorded demonstration, the instructor exited the cockpit and all further instruction was accomplished from the instructor/operator console. The only exception to this procedure was for the no gunsight group, where in order to familiarize the subject with the use of the gunsight, a second demonstration (this time with gunsight) was presented between trials 5 and 6.

All groups performed 15 trials without interruption. For the Standard Group, all 15 trials were performed with the gunsight, but not with the predictor cue present. For the predictor group, the predictor cue was continuously present during all 15 trials. For the No Gunsight group, the predictor cue was never available. For the first five trials, the gunsight was not available either. For the No Gunsight group, the gunsight was introduced on trial 6 and was present for all remaining trials.

Instructors seated at the console were given a planar view of the ground track and final leg segment of the maneuver as well as a graphic display of the bomb circle and impact point with indications of the following release parameters (airspeed, heading, altitude, dive angle, g-load). No restrictions or specific instructions were given to the instructor as to the manner in which this information should be used.

Following the 15th trial, subjects exited the simulator for a short break and final critique by the instructor prior to reentering the cockpit for the 10 final trials which were conducted in the absence of any instructor feedback. For the final 10 trials, subjects in all three groups performed under the same conditions (i.e., gunsight, no predictor cue, and no instructor feedback). Dependent measures collected consisted of circular error and release parameters.

RESULTS

The results of the present study will be presented in three sections. The first section will examine the relationship of various measures of flying experience to circular error measures of bombing performance. The second section will present differences between treatment groups in terms of measures of circular error. The third section will present differences between treatment groups in terms of release parameters.

Measures of Flying Experience and Bombing Performance

Prior to comparing treatment groups in terms of bombing performances, groups were compared for possible significant differences in flying experience. Neither of three different measures of performance were found to be significantly different. Groups did not differ in terms of total flying hours ($F(2,19)=0.5676$, $p > .05$); T-37 flying hours ($F(2,19)=3.30332$, $p > .05$); or the ratio of T-37 to total flying hours ($F(2,19)=1.35116$, $p > .05$). With one exception, none of the above measures of flying experience was found to be correlated significantly with bombing performance, when bombing performance was taken as the mean circular error over trials 20-25. The one exception was for the predictor group, where the ratio of T-37 to total flying time was found to be significantly correlated with circular error ($r=-.9165$, $df=4$, $p < .05$) for trials 20-25. Comparisons, however, between this measure of flying experience for subjects in the predictor group with performances over Blocks B1-B3 did not reveal the presence of a significant relationship. Thus, despite the wide range of flying experience represented across the three subject groups, the results indicate that the experience variable was not systematically related to performances in the present study.

Differences in Circular Error Scores

The results of primary concern deal with the differences between treatment groups in terms of mean circular error. As can be seen in Figure 1, all groups show a significant decrease in circular error scores over the first 15 trials. Mean circular error and standard deviation in circular error by blocks of trials are given in Table 2.

TABLE 2

MEAN CIRCULAR ERROR (FEET)

Group		Blocks of Five Trials				
		1-5	6-10	11- 15	16-20	21-25
Stand (N=11)	X=	314.74	227.14	205.22	144.80	192.76
	s.d.=	251.99	177.12	129.22	96.25	111.63
Pred (N=6)	X=	405.13	237.87	212.60	316.67	170.13
	s.d.=	247.49	167.42	164.22	172.05	138.63
No Gun sight (N=5)	X=	456.76	152.28	126.60	170.40	167.20
	s.d.=	282.86	122.67	83.95	89.68	76.85

Not only was an improvement in accuracy noted over the first three blocks of trials, but also a decrease in the variability of the bombing performances . The difference, however, between circular error scores for the predictor and standard groups was not found to be statistically significant ($F(1,15)=0.363$, $p=.5619$). Neither was the difference between the standard group and the no-gunsight group statistically significant ($F(1,14)=.004$, $p=.9469$). The failure to find a difference between the standard and no-gunsight groups is probably accounted for by the poor first block performance of the group performing the task without the gunsight. When a comparison is performed between the standard and no-gunsight groups for blocks 2 and 3 (i.e., trials 6-15), the difference approaches statistical significance ($F(1,14)=2.528$, $p=.1274$).

Discontinuation of instructor feedback produced no significant effect upon the performances of the no-gunsight and standard groups. It must be remembered that the no-gunsight group and the standard group were practicing under identical conditions for trials 6-15. As is seen, however, in Figure 1, abrupt removal of the predictor cue produced an approximate 50 percent decrease in accuracy. This decrease in accuracy was quickly overcome, however, so that by the last block of five trials, little if any difference can be noted between the three groups. The effect of removing the predictor cue is instructive, inasmuch as the absence of any difference between the standard and predictor groups during the first 15 trials gives little evidence that the cue was even being utilized. The marked disruption, however, following its removal gives evidence to the contrary.

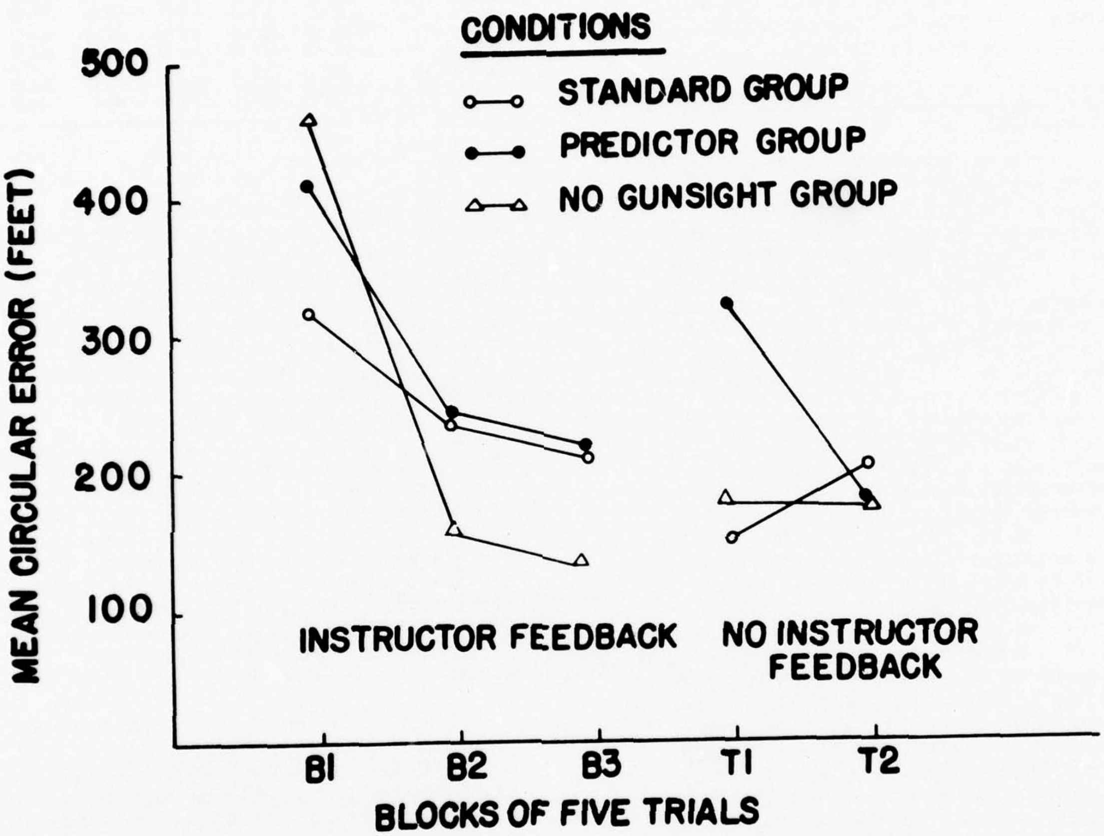

Figure 1

Circular Error Across Trials As A Function Of Instructional Conditions

Differences Between Groups in Terms of Release Parameters

Means and standard deviations for each of the five release parameters are given in Table 3.

Standard and predictor cue groups were found to differ significantly ($F(1,15)=4.619$, $p=.0461$) in dive angle variability over trials 1-15. While circular error scores were not found to differ significantly over these blocks of

TABLE 3
RELEASE PARAMETERS
MEANS

RELEASE PARAMETERS		BLOCKS OF FIVE TRIALS 1-5	6-10	11-15	16-20	21-25
S		349.37	349.84	349.70	346.14	248.90
HEADING	P	347.03	348.60	347.23	348.23	333.07
(350 degrees)	NS	349.92	348.92	349.12	350.68	410.00
	S	3012.95	2909.58	2840.92	2910.65	2886.32
ALTITUDE	P	2992.37	2969.99	2965.83	2965.07	2984.70
(3000' AGL)	NS	2965.48	2839.64	2932.43	2965.43	3012.99
	S	1.10	1.18	1.12	1.11	1.20
G LOAD	P	1.32	1.23	1.28	1.28	0.90
(0.09)	NS	1.08	1.20	1.18	1.30	1.21
	S	308.59	308.71	309.94	309.25	308.64
AIRSPEED	P	308.80	306.40	304.87	307.60	303.90
(300 KIAS)	NS	309.96	312.48	310.24	311.36	307.64
	S	28.00	29.16	29.70	30.11	29.56
DIVE ANGLE	P	28.83	29.00	27.33	28.00	28.03
(30 degrees)	NS	30.12	29.24	29.52	29.12	27.84

STANDARD DEVIATIONS

RELEASE PARAMETERS		BLOCKS OF FIVE TRIALS 1-5	6-10	11-15	16-20	21-25
	S	3.17	2.78	2.39	6.45	2.45
HEADING	P	2.55	3.12	4.66	2.58	2.25
	NS	3.84	1.91	1.64	2.02	1.54
	S	311.63	264.28	204.79	149.11	161.02
ALTITUDE	P	283.30	392.65	283.94	168.88	186.86
	NS	206.56	151.77	131.28	131.17	136.81
	S	0.50	0.48	0.31	0.16	0.31
G LOAD	P	0.41	0.35	0.42	0.42	0.28
	NS	0.39	0.33	0.29	0.22	0.33
	S	10.05	7.47	4.77	6.84	4.72
AIRSPEED	P	7.76	8 93	9.27	4.48	5.30
	NS	6.34	4.59	4.76	4.76	3.24
	S	3.27	2.78	2.21	2.50	2.21
DIVE ANGLE	P	4.85	3.23	3.38	2.54	2.11
	NS	3.11	2.10	1.80	1.39	1.86

trials, the predictor group showed as much as 53 percent more variability in dive angle (block 3) than the standard group. Comparisons between the standard and predictor groups for trials 16-25 when the predictor cue was removed and all subjects performed in the absence of any instructor feedback showed a tendency for mean dive angle to be shallower for the predictor group than for the standard group. This difference, however, was not statistically significant ($F(1,15)=2.887$, $p=.1068$). In attempting to isolate from measures of release parameters the basis for the disruption in accuracy caused by removal of the predictor cue, groups were compared over block B3 and block T1. The only difference, in terms of release parameters, that was identified was a significantly greater variability in g-loading for the predictor group as compared to the standard group ($F(1,15)=4.932$, $p=.0402$). While g-loading was approximately 35 percent more variable for the predictor group on block B3, removal of the predictor cue on block T1 caused the variability in g-load for the predictor group to increase to approximately three times that of the standard group.

While differences between the standard group and the no gunsight group were marked in terms of circular error, differences in terms of release parameters were more subtle. In fact, only one comparison between the two groups for trials 1-5 revealed a difference that even approached statistical significance. This was in the case of altitude variation upon release where there was a trend ($F(1,14)=2.834$, $p=.1164$) toward greater variation in altitude in the standard group as compared to the no gunsight group.

DISCUSSION

Comparisons of performances in the present study with those reported by Gray and Fuller (1977) reveal an approximate 30 foot difference in mean circular error for subjects performing the 30 degree task under similar conditions. In light of the variability associated with individual performances in the present study, a 30 foot difference would be considered to have occurred by chance. It must be remembered too that the Gray and Fuller (1977) study was conducted to demonstrate the limits to which this type of task could be taught in the simulator and in so doing employed experienced instructors within the context of a developed syllabus. The present study employed the air-to-surface task because of its convenience as a benchmark task against which alternative instructional treatments could be evaluated. Therefore, the level of performance attained was secondary to the sensitivity of the task to any main effects in terms of instructional treatment conditions.

These data are instructive too for several reasons. First, from the standpoint of flying training simulation, these data demonstrate that active control over cues inherent in the visual environment of the student (in this case, the gun sight itself) may lead to better performance than the augmentation of that environment with cues intended to "aid" the student in performing a difficult task. In the present study, control over stimuli in the student's visual environment proved to be more effective than attempts to alter the difficulty of a complex tracking task through augmented visual feedback.

Secondly, the present data clearly showed that the abrupt removal of an augmented visual cue (i.e., the predictor cue) can produce a significant decrease in accuracy and an accompanying increase in variability when no provision exists for gradually fading out that cue. The results of the present study clearly point out the need in future systems for more active control over the stimuli present in the training environment. . . not only their presence or absence, but also their discriminability (e.g., intensity, etc.). It is clear too that before such active control can be incorporated into adaptive approaches e.g., Williges and Williges, (1977), research must address how such changes are most effectively made contingent upon student performance.

A third point concerns the poor perfomance obtained from subjects using the predictor cue. While the disruption in performance upon removal of the cue was expected, the failure of the predictor group to initially outperform the standard group was totally unexpected. While subjects were instructed to treat the cue as an "aid" that after 15 trials would be removed, the evidence is clear from the disruption that occurred on Block T1 that the cue was being used during practice on Blocks B1-B3. It, thus, does not appear to be the case that the instructions biased subjects in the direction of not using the cue. It may be that although such a cue may serve to facilitate the performance of the naive student, its use with experienced pilots such as those in the present study

served to increase rather than decrease the difficulty of the air-to-surface task.

The results, however, do not preclude the potentially effective application of such predictor cues with pilots of lesser experience. For example, a visual cue similar to that used in the present study but instead depicting the "aimpoint" of the aircraft (i.e., the point at which the aircraft would hit the ground given its present configuration) might prove to be effective not only in the bombing task but in acquisition of the landing task as well. Research is continuing at the Air Force Human Resources Laboratory's Flying Training Division into different and more effective means of manipulating the visual environment of the pilot.

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ADVANCED SIMULATION FOR NEW AIRCRAFT

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ABSTRACT

The traditional procurement process for new military aircraft simulators results in a long, costly, and dangerous delay in availability of training equipment, after introduction of the aircraft. The Advanced Simulator for Pilot Training (ASPT) of the Human Resources Laboratory, Flying Training Division has been modified to provide early simulation of the A-10 and F-16 aircraft. The resulting advance in A-10 program development has been dramatic. Although not yet fully operational, the ASPT F-16 simulation will provide at least comparable benefits for F-16 training program development. The ASPT modification program demonstrates a reasonable method of greatly improving availability and effectiveness of simulator training programs.

THE PROBLEM

Military aircraft simulators, more aptly described as weapon system trainers, are an integral part of the modern operational flight training system. These devices provide the capability to acquire (and practice) outside the aircraft, skills, both cognitive and motor, critical to the successful completion of tasks ranging from aircraft transition training to advanced weapons delivery and air-to-air combat; however, current simulator procurement schedules seriously limit simulator design and effective utilization within the overall training program. At present, the time delay from the initial integration of the aircraft into the operational inventory until the corresponding simulator system is available for training is normally about five years. This lag adversely affects not only the energy, equipment, and manpower costs within the operational training schedule, but also the design of the weapon system trainer itself. Virtually every important simulator (and syllabus) design decision must be based on experience, judgement, or guesswork - everything except concrete evidence founded upon first-hand knowledge. Although simulation is widely used during preliminary engineering design and aircraft development, these simulations are not suitable for training system development. These inputs are provided during the first few years of operational development of a given aircraft, when often by trial and error, marked at times by loss of life, training problems are gradually eliminated. We believe that this dangerous transition period can be eliminated by using a training system development simulator. A reasonable simulation of the new aircraft coincident with operational deployment could be used to address training issues, as well as simulator design issues prior to their requirement for use.

SOLUTION

The solution to this problem involves, as we see it, the following organizational and engineering elements:

a. A simulation facility (or combination of facilities) with sufficient potential to construct, in a short period of time, reasonable models of a wide variety of aircraft and aircraft task environments.

b. A close cooperation between the aircraft development group, the Command Instructional System Development team, the simulator manufacturer having responsibility for the final weapon

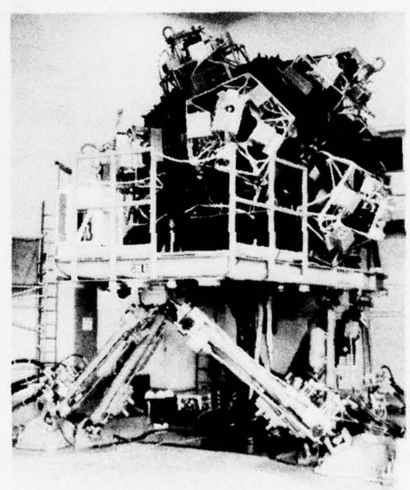

FIGURE 1.
ADVANCED SIMULATOR FOR PILOT TRAINING (ASPT), SHOWING 60 INCH, SIX DEGREE OF FREEDOM, SYNERGISTIC PLATFORM MOTION SYSTEM AND WRAPAROUND COMPUTER IMAGE GENERATED VISUAL DISPLAY.

systems trainer, and the designated facility where the preliminary training and research will occur.

The simulation facility should support, as a minimum, the following basic systems:

(1) Flight dynamics.

(2) Basic aircraft instruments and controls.

(3) Wide field of view, high resolution visual.

The systems (1)-(3) are absolutely required in all critical aircraft tasks. Additionally, to be effective, a research facility should have most or all of the following:

(4) Six degrees of freedom motion.

(5) G seat.

(6) G suit.

(7) Other Aircraft/Environment systems such as sound, navigation, communication, hydraulics, etc.

(8) An advanced instructor-operator station with automated student performance measures.

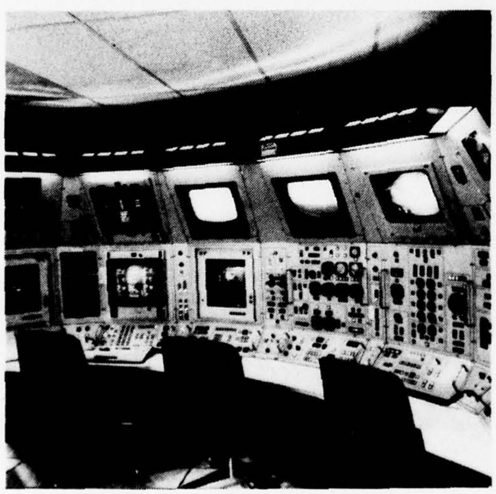

FIGURE 2.

ASPT ADVANCED INSTRUCTOR OPERATION. THROUGH THIS STATION, THE RESEARCHER CONTROLS THE ASPT SIMULATION EXPERIMENTATION. USING ALPHANUMERIC, VECTOR GENERAL GRAPHICS DISPLAYS, AND A WIDE VARIETY OF INSTRUMENTS, RECORDERS AND CONTROLS, ENTIRE MISSION PROFILES CAN BE CAREFULLY CONTROLLED.

The HRL ASPT has all of these features and is admirably suited for training program research and development,(Figures 1-6.)

Most important of all, the facility should have an extensive performance measurement capability backed by sufficient computer capacity to support such special research requirements specific to a given operational aircraft.

FIGURE 3.

DISTRIBUTED PROCESSOR SIMULATION SYSTEM. THIS COMPUTATIONAL NETWORK PROVIDES THE CAPABILITY FOR AN AIRCRAFT/ENVIRONMENTAL SIMULATION AT A MINIMUM OF 30 HZ FOR ALL AEROSPACE VEHICLES EXCEPTING CERTAIN HELICOPTER SIMULATIONS, WHILE PROVIDING SUFFICIENT BACKGROUND TIME TO SUPPORT PARALLEL RESEARCH AND ENGINEERING DEVELOPMENT CAPABILITY.

Care must be taken to limit the scope of the simulation development. Because the timing of the research is critical to the vitality of the entire projects, we recommend a multiphase effort based on the critical task approach. Within this philosophy, the Phase I simulation would be a "no frills" model capable of performing, say, transition tasks. Only those instruments, controls, and accessory equipment essential to the accomplishment of the Phase I objectives need be simulated.

PAYOFFS

The payoffs associated with this approach, as we see them, are direct force readiness, as measured by the capability of a group of pilots to perform their assigned mission, will be greatly increased. Transition training will be safer and more efficient. Emergency situation training, perhaps impossible to practice safely in the aircraft, can be provided in the simulator. The greatest areas of training payoff will naturally be associated with the principally cognitive tasks (such as those in air-to-air or air-to-surface attack). In addition to the enhanced safety and improved training, large amounts of fuel, manpower, and equipment dollars will be conserved, a real bonus for the operational commander. At the same time, research payoffs will be equally great. Major design considerations for the weapon systems trainer can be fully determined and this information provided to the simulator contractor. High-cost hardware issues, such as visual system design, instructor operator station design, and even motion cueing systems alternatives, can be effectively determined. At the same time, issues related to both simulator and aircraft utilization for operational training, including syllabus development, course content, task sequencing, development and validation of performance assessment measures will be possible.

RESULTS

To date, the Flying Training Division, Air Force Human Resources Laboratory, has successfully applied the approach outlined in this paper to the A-10 aircraft, using the ASPT as the development simulator, and is preparing a similar effort for the F-16 aircraft. The A-10 Phase I simulation on the ASPT, while austere, has been successful. In general terms, the objectives of the ASPT A-10 Phase I conversion were:

(1) To provide interim transition training for A-10 pilots in the period before delivery of the A-10 WST.

(2) To provide introductory surface attack training during the same period.

(3) To assess advanced training features of the ASPT instructor-operator console for possible adaptation to future fighter/attack simulators.

(4) To develop automated objective performance measures of fighter/attack pilot performance.

(5) To develop the A-10 simulator training program and provide hands on experience for A-10 simulator instructor pilots.

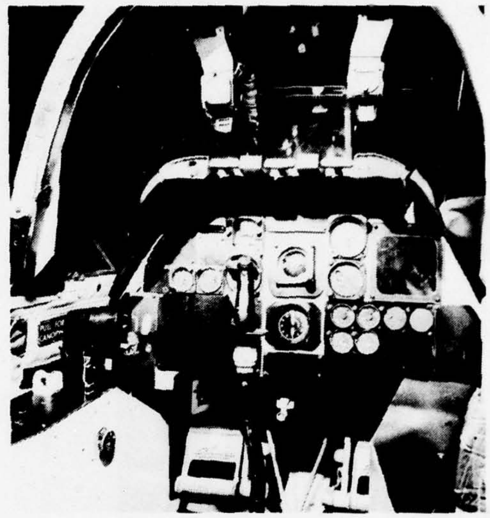

FIGURE 4.

ASPT/A-10 PHASE I COCKPIT SIMULATION. THIS PICTURE DEMONSTRATES THE LEVEL OF SIMULATION REQUIRED TO ACHIEVE TRANSFER OF TRAINING GOALS FOR PHASE I. PICTURED ELEMENTS INCLUDE PRINCIPAL AIRCRAFT CONTROLS, INSTRUMENTS, AND HEADS UP DISPLAY.

All of these objectives were met satisfactorily; in most cases, results were considerably better than were expected from the rather austere Phase I simulation.

TRANSITION TRAINING

By May 1978, 17 B course students had received transition training in the ASPT A-10. All of these pilots successfully transitioned into the airplane. Although numbers are too small for statistical significance at this time, it appears that the ASPT trained pilots are the equivalent of about two aircraft sorties ahead of where they would be without ASPT training. This undoubtedly is at least partially due to the extensive cooperative effort by instructor pilots from Davis-Monthan AFB and AFHRL engineers to assure that the A-10 performance and handling qualities were as faithfully simulated as available data would permit.

The transition training results for the first class were:

(1) Of 47 rides, only one failed.

(2) In the first 67 rides, there were no unsatisfactory patterns or landings.

(3) In the first 67 rides:
50% rated 01 (Fully Qualified).
50% rated 02 (Qualified with Additional Training).

FIGURE 5.

ASPT PHASE I RUNWAY SIMULATION. THIS AUSTERE DATA BASE SHOWS THE LEVEL OF DETAIL REQUIRED FOR SUCCESSFUL TRANSITION TRAINING FOR THE A-10 PROGRAM.

INTRODUCTORY SURFACE ATTACK TRAINING

Results of the introductory surface attack training are spectacular. The ASPT A-10 proved to be exceptionally effective for bomb and gunnery range instruction - in fact, the simulator is more effective, sortie for sortie, than the airplane.

The surface attack training results for the first class are:

Event	Needed to Qualify (CEP)	First Class Average (CEP)
30 Deg Dive Bomb	140'	80'
20 Deg	175'	65'

A number of factors probably contribute to the high effectiveness of the ASPT A-10. Prerecorded demonstration runs show the student exactly how to achieve best results. Using freeze and reset features, many more practice runs are possible in the simulator than in the airplane. The student is immediately informed of the results of each run, as well as the exact conditions that existed at release time.

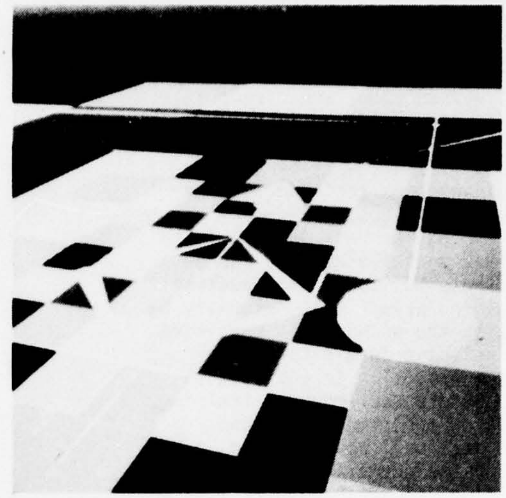

FIGURE 6.

CONVENTIONAL BOMBING RANGE. THIS PICTURE SHOWS THE APPROXIMATE LEVEL OF DETAIL REQUIRED TO TRAIN CONVENTIONAL BOMBING TASKS.

ADVANCED TRAINING FEATURES

As mentioned above, the ability to record and play back demonstration flights appears to have great training value, particularly for single seat aircraft such as the A-10. The related capability to record a student flight and play it back later for a critique also seems to have great promise.

The ability to freeze the action at any point and to reset rapidly to chosen initial conditions allows concentrated practice and assessment of procedural errors.

Use of automated performance measures (discussed below) assures objective evaluation of performance.

A number of such training features were evaluated during the ASPT A-10 Phase I, and recommendations for future fighter/attack simulators are being developed. This research will continue during Phase II. Evaluation of the

training value of such features as "faster than real-time" operation and special training displays such as continuous display of impact point is under consideration.

AUTOMATED PERFORMANCE MEASURES

There are many reasons for developing automated measures of student performance:

(1) The student is assured of accurate, impersonal, objective assessment of his performance.

(2) Many more aspects of performance can be evaluated automatically than is possible for a single instructor pilot.

(3) Instructor pilot workload is eased, permitting him to devote his attention to instructional duties.

In general, performance measures must be specially developed for each aircraft and each task. Following is a list of A-10 tasks for which automated performance measures have been developed and used:

A-10 PERFORMANCE MEASUREMENT TASKS

TRANSITION

Takeoff, climb and level off
Slow Flight
Lazy 8, Aileron Roll (clean & 40% speedbrake)
Loop, Cuban 8, Split S
Simulated flameout pattern
Straight-in pattern
Normal overhead (360^{o}) pattern
Closed normal pattern
Closed no flap pattern
Closed simulated single engine pattern
Re-entry to normal overhead pattern

AIR-TO-GROUND

30 Degree Dive Bomb
20 Degree Low-Angle Low-Drag Bomb
15 Degree Low-Angle
Low-Angle Strafe
High-Angle Strafe
Low-Angle Low-Drag Pop-Up
Low-Angle Pop-Up
Low-Angle Strafe Pop-Up
Hung Bomb Pattern

SIMULATOR TRAINING PROGRAM

At this time, the A-10 simulator training syllabus has been used with 17 students. Ten instructor pilots have participated in the training program. Without the ASPT A-10, this status would not have been achieved for at least two more years. Experience with an A-10 simulator including a full visual system would not be possible for at least five years. Thus the A-10 training program has been advanced by 2-5 years, with a very substantial improvement of the effectiveness of the A-10 aircraft.

CONCLUSIONS

We have presented, and to a large degree, tested and verified a managerial tool for solving the problem of time delay between the deployment of an operational aircraft and its corresponding weapon system trainer. This approach is seen to have large payoffs in terms of direct research and design benefits, as well as a positive impact force readiness, pilot safety, and fuel expenditure. We have restrained throughout this discussion from detailing any particular potential engineering mechanization of this plan, as such a mechanization depends primarily on the aircraft (or system) simulated and the engineering characteristics and capability of the host facility. We feel that the procedure presented is a natural extension of the use of simulation to solve training problems and, as such, should become a permanent part of all future aircraft development and deployment schedules.

ABOUT THE AUTHORS

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DR. LAURENCE E. FOGARTY is Professor and Director of the Simulation Center at the University of Michigan. He is presently working at Air Force Human Resources Laboratory, Williams Air Force Base, Arizona under a research grant on the Advanced Simulator for Pilot Training (ASPT) A-10 and F-16 projects. He holds a B.E.E. degree from Montana State University and a Ph.D. in Aeronautical Engineering from Cornell University.

MICROCOMPUTER BASE FOR CONTROL LOADING

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INTRODUCTION

Simulator designers have been faced with two familiar problems throughout the digital age of simulation; namely, framing time crunch and discrete system anamolies associated with models of analog systems. This project has been oriented to impact both of these problem areas as well as to produce a piece of gear suitable for general simulator usage. The primary rationale for conducting this research has been to distribute the intelligence of the simulator to points where it is needed and thus relegate the host computer to the role of a system manager. The control loading task was selected because of its suitability for distributed processing and because of its need for frame rates higher than the nominal 15 to 30 frames-per-second simulator rate. The U.S. Air Force[1] specified that the results of this effort must contain data from which it can write specifications and select future simulator configurations.

THE CONTROL LOADING TASK

Pilots have always and, no doubt, will always complain that the simulator doesn't quite "feel" like the aircraft. This tendency for precise control on the part of the pilots is often offset by the astute engineer who taps on the side of a control cabinet and then says "How's that feel now?"

The "feel" which the pilot experiences in his control system is usually composed of six independent forces: spring, breakout, travel limit, viscous friction (damping), Coulomb friction, and velocity limit. The first three forces are functions of displacement whereas the later three are velocity functions. Occasionally inertia, which is an acceleration term, is also required for complete control synthesis. Another indispensible parameter is the deadband which the pilot experiences around a variable trim setting. In addition, the airframe may very well influence this "feel" through actuator, bobweight and/or control surface force feedback.

The selected hardware configuration for this project includes a force-type control loader equipped with position and velocity transducers as shown in Figure 1. A microcomputer is employed to calculate the various forces mentioned above based on inputs from the control loader's transducers and selected parameters from the "host" computer, a Honeywell 316. The control loader selected for the task was the McFadden Electronics 392A[2] 3-axis control loader and the microcomputer was an Intel System 80/20. In order to provide the project with direction and credibility, the A-10 was selected as the study aircraft. This selection was made primarily on the basis of the availability of suitable control loading data.

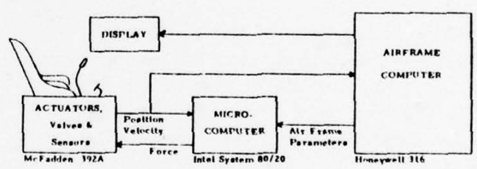

Figure 1. General Configuration Diagram

PARAMETRIC ANALYSIS

Each of the individual forces in some way models an element of the aircraft control system. These forces are, in general, additive as shown in Figure 2, even though they may be the result of nonlinear processes. However, the total solution requires that these forces be logically connected to accurately represent the fully integrated control system.

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[1] Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio.

[2] Control Loader was loaned at no-cost to the University of Dayton or the U.S. Government.

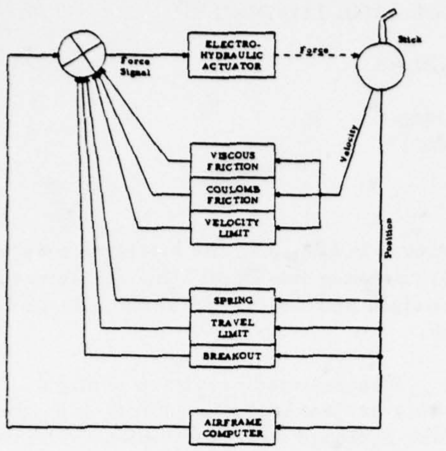

Figure 2. Force Component Diagram - Single Axis

For example, consider the forces generated for a single axis (e.g. pitch control) which has a deadband due to rigging slack at the control stick. The pilot would therefore experience nearly zero force within the deadband which is described as follows:

$$F_{TOT} = [F_{SP} + F_{VI} + F_{VO} + F_{BR}]\, U(DB) + F_{TR} + F_{VEL} + F_{AC} \qquad (1)$$

where the above terms stand for total, spring, viscous, coulomb, breakout, travel limit, velocity limit and aircraft related forces, respectively. The unit operator "U" indicates that the quantities within the brackets are nil in the deadband.

As an alternate example, consider a case where the rigging slack is remote from the stick. The Coulomb friction due to pulley drag may then be placed outside the influence of the deadband with the resultant force equation

$$F_{TOT} = [F_{SP} + F_{VI} + F_{BR}]\, U(DB) + F_{CO} + F_{TR} + F_{VEL} + F_{AC} \qquad (2)$$

These two examples represent wiring differences in an analog system but only software differences in a digital system, an important consideration in a research or development environment. For the A-10 model, the deadband is very small but follows the format of Equation 1. The complete pitch force equation then becomes

$$F_{TOT} = -[\underbrace{K_S X_D}_{\text{spring}} + \underbrace{2.5 \text{ sign } (X_D)}_{\text{breakout}} + \underbrace{1.5 \text{ sign } (\dot{X})}_{\text{coulomb}} + \underbrace{64 \dot{X}}_{\text{viscous}}]\, \underbrace{U(DB)}_{\text{deadband}} - \underbrace{K_T X_T}_{\text{travel}} - \underbrace{(3 N_Z + .026 \ddot{q})}_{\text{bobweight}} \qquad (3)$$

where X_T is the displacement (in inches) past a travel limit, X_D is the displacement past a deadband limit and $\dot{X}$ is the velocity in inches-per-second. N_Z and $\ddot{q}$ are the normal and angular accelerations from the airframe computer which produce the control system bobweight effects. K_S represents five nonlinear spring coefficients (breakpoints) which characterize the A-10. Similarly, K_T represents a large gain coefficient which produces the large feedback forces for small amounts of travel (X_T) past the limit. The force is calculated in pounds and, of course, requires a sign change to produce the required opposing force. Equation 3 is obviously stylized and requires special handling due to the nonlinearities involved and must be properly scaled. The nonlinearities are discussed below and the microcomputer processing, which was performed entirely in integer format, is discussed in the software section.

In order to handle the nonlinearities of such a system, the frequency response of the control loader must be considered. The nominal 30 frames-per-second for digital simulators is usually sufficient to make the pilot believe that he is flying in a parallel, analog world as evidenced by his visual displays. However, the pilot's tactile mechanism is capable of much higher frequency response. Empirical studies conducted on the McFadden control loader revealed frequency components of 1000 Hz and higher. As one might expect, these components are experienced at the breakout and travel limits where forces suddenly change. To satisfy the ground rules of information theory put forth by Shannon, the microcomputer should ideally be framing at a 5000 Hz rate or better. However, this project demonstrated that quite acceptable results can be had at 120 frames-per-second by judiciously choosing compensation schemes. That is, by optimizing lead, lag, and gain coefficients in the individual component force calculations relatively sharp breakouts and stops were obtained.

Various techniques were attempted to achieve the proper compensation, including a Tustin recursion method to approximate the desired transfer function. However, the final product was a result of an educated cut-and-try effort. For example, consider the travel limit force component which can be expressed mathematically as a recursion relationship

$$F_{TR} = K_T[X_T(N) + X_T(N-1)] + K_L\dot{X} \qquad (4)$$

In the digital implementation, the needed lag term is obtained by employing both the present frame value for travel limit displacement $X_T(N)$ and the previous frame value $X_T(N-1)$. The gain is controlled by the value of K_T and the needed lead term is obtained from the available velocity signal $\dot{X}$ which is modified by the constant K_L. The unscaled magnitudes of K_T and K_L and the number of terms in the recursion portion of the lag component were determined empirically with the final values set at $K_T = 6$ and $K_L = 2$. The breakout term of Equation 3 required a slight lag compensation augmented by a lead term ($K_B = 0.3$) and was empirically structured as

$$F_{BR} = 2X_D + K_B\dot{X} \quad \text{for} \quad 2X_D < 2.5 \qquad (5a)$$

$$= 2.5 \text{ sign } (X_D) + K_B\dot{X} \quad \text{for} \quad 2X_D \geq 2.5 \qquad (5b)$$

Similarily, the Coulomb friction term required compensation to offset a tendency to "dither" because of its dependency on the sign of the velocity. In this case a simple lag was implemented by employing the velocity value as follows:

$$F_{CO} = \dot{X} \qquad \text{for} \quad |\dot{X}| < 1.5 \qquad (6a)$$

$$= 1.5 \text{ sign } (\dot{X}) \quad \text{for} \quad |\dot{X}| \geq 1.5 \qquad (6b)$$

THE HARDWARE

One of the important driving factors in this study was that the hardware must be composed of off-the-shelf components to the greatest extent possible. A preliminary analysis showed that four primary functions must be supplied by the hardware; namely, central processing, analog input, analog output, and high-speed mathematics. Figure 3 illustrates the hardware configuration which employs the System 80/20 components from Intel Corporation. Each of the four blocks represents a bus compatible circuit board which resides in the System 80/20 chassis. The only hardware modifications performed were wiring options which are incorporated on the individual boards for customizing purposes.

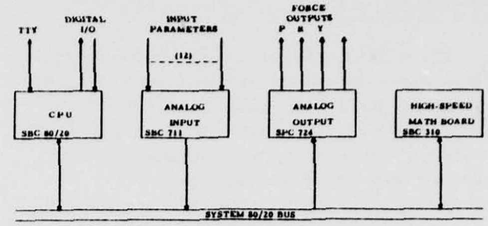

Figure 3. Hardware Configuration

The CPU is an 8-bit processor with 2K of RAM (random access memory) and with 8K of ROM (read only memory) and has a clock cycle time of 490 nanoseconds. The analog boards convert analog signals with 12-bit (0.025%) accuracy and were configured to handle conventional analog signals ($\pm$10v) and offset binary (2's complement) digital values. The high-speed mathematics unit provides both integer, and floating point operations with appropriate 16 and 32-bit accuracies. Additionally, the CPU provides a teletype (TTY) interface for changing equation coefficients and digital parts for trim switch inputs and for frame-time monitor outputs.

The interfaces with the control loader and host computer (as shown in Figure 1) were entirely analog due to contractual requirements for generality. An ideally flexible system would have a digital host/microcomputer interface for parameter passing and software downloading. Each of the three axes required four input parameters to satisfy its force equation (e.g. Equation 3), stick displacement and velocity, airframe normal and rotational accelerations. The analog input board, which has a capacity for 16 analog inputs, converted the required 12 analog values in approximately 800 microseconds. Three of the four available analog outputs were employed to drive the respective control loader force inputs for each axis, pitch, roll, and yaw.

THE SOFTWARE

The entire control loader software was written in the Intel high-order microcomputer language called PLM, with the exception of the analog-to-digital conversion routine which was performed in assembly language. The programs were structured into a utility module and a simulator module. As the name implies the utility module provided system support in the form of calibration and test routines, system interface procedures, and system initialization. The simulator module contains the frame rate generator, simulator initialization routines, the analog scan/convert routine, and the simulator equations themselves. The executable machine code was placed in PROM (programmable read only memory).

Perhaps the most unique feature of the software structure is that the calculations were carried out entirely in integer format resulting in a very significant reduction in processing time required for each frame. As seen in the above equations, the only mathematical processes required are addition, subtraction and multiplication. Since both the analog input and analog output boards operate with 12-bit precision, the microcomputer was designed to employ 16-bit precision (two 8-bit words). The PLM language and the high-speed math board both support 16-bit operations of this nature. All parameters were scaled to keep the values within these limits. The equation coefficients were scaled to be either integer values or fractional values less than 1. The fractional coefficients were rescaled upward by multiplying them by 2^{16} (65536). The result of an integer multiplication (a 32-bit value in the high-speed math board) was scaled back down by 65536 by taking only the most significant 16 bits from the result register. The only drawback to this method of processing was the unsigned nature of the multiplication, thus requiring procedures for sign conversion of negative quantities.

CONCLUSIONS

A purely objective evaluation of an engineering system usually involves graphs, strip charts and computer printouts. Thus, the usual static and dynamic tests were carried out with excellent success. However, the last word on a system involving "feel" must be subjective. Those who were able to experience the "feel" of the control loader employing the microcomputer base considered it to be of "good" quality compared to the same system employing the analog base supplied with the McFadden system (which is easily judged as excellent). The microcomputer, of course, was performing additional airframe related calculations which the standard analog system does not. The only difference in quality seemed to be at the stops and breakouts. Due to the limited frequency response of the microcomputer system, the respective gains were held relatively low for stability reasons. This practice resulted in the discontinuities being less "sharp" than the analog based version. On the other hand, the system was judged by most to be suitable for direct application in existing simulators.

RECOMMENDATIONS

This study has clearly demonstrated the feasibility of microcomputer control. The only consequentional recommendation as a result of this study would be to increase processing frame rate by a factor of five to six times. This improvement is within the capabilities of present technology but not exactly "off-the-shelf." The most immediate thought would be to use a 16-bit processor instead of the 8-bit processor but this would result in only a 50% to 60% speed improvement without any other changes. The most significant improvement would be to use a multiprocessor architecture with a processor devoted to each axis. Another dramatic speed improvement could be obtained if a hardware multiply unit was employed which performed signed (as opposed to the present unsigned) integer multiplication. If these three changes were coupled with improvements in microcomputer technology (a daily occurrence), frame rates up to 1000 per second are within reach.

ABOUT THE AUTHOR

DR. GERRY ALBERS is an Associate Professor in Electrical Engineering at the University of Dayton. He is currently performing research in the area of simulator design and technology. He is a former T-38 Instructor Pilot and his professional experience also includes digital system design, system simulation and modeling, engineering education, and private consultation. His most recent research programs include the design of a microcomputer base for control loaders and the system design and math modeling for the Boom Operator Part Task Trainer, an Aeronautical Systems Division simulator design for SAC.

A NEW APPROACH FOR ELECTRONIC WARFARE (EW) AIRCREW TRAINERS

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SUMMARY

This paper discusses the ever-increasing role of EW training as an outgrowth of the expanding emphasis on EW in our national defense program. It discusses the basic requirements of EW aircrew trainers and the solutions available. One solution is the hardware stimulation approach, employing racks of pulse and scan generators to provide RF or video inputs into operational EW equipment. The other solution is the software simulation approach, modeling the emitter environment and EW equipment in a general-purpose computer and providing outputs to drive the EW equipment displays and control panels. The software approach has significant advantages in hardware cost and complexity, instructor/operator interface, reliability, maintainability, and ease of update and modification. However, fears of modeling the highly sophisticated EW equipment and environments have kept this approach from being used. This paper demonstrates that the software approach can be successfully employed. A discussion of an RWR training device recently developed by ATI and using the software approach is contained in this paper. Finally, a discussion is presented on the application of the software approach to new and future EW systems.

INTRODUCTION

Ever since the development of radar, the role of electronic warfare (EW) in our national defense picture has been growing at an unprecedented rate. New airborne and ground-based EW systems have evolved with ever-increasing capabilities and complexities. Our pilots and EW system operators have a tremendous burden in keeping pace with this growing technology. A major portion of our defense relies on their ability to operate their equipment and perform their missions in varieties of wartime and peacetime conditions. Therefore, it is imperative that these EW system operators and pilots obtain rigorous and up-to-date training to achieve and maintain proficiency and combat readiness.

There are two basic methods by which this much needed training can be provided. First, it can be accomplished in the field with actual sites and live emitters. In the case of airborne EW training, this would involve actual equipment operating against live ground sites, as on a flight test range. This approach to EW training has the advantage that everything is real. The tracking, propagation, polarization and antenna installation effects are implicit. On the negative side are a host of items, headed by cost. Training of a single person requires the support of an entire flight test range with operators at each site, coordination personnel and large amounts of fuel. Furthermore, the entire training session has limited realism in terms of the make-up of the scenario, since there is currently no test range that approaches postulated signal densities of even the most optimistic European or Middle East EW engagement scenarios. The lack of portability of the sites introduces further problems in the ability to effectively train, since the student regularly encounters the same situation.

The same arguments, of course, apply to EW training in environments other than airborne. In a field exercise, mobile ground-based ELINT sites can be positioned around a number of live sites to train operators to efficiently intercept signals of interest and determine signal characteristics and perform DF computations. This type of training suffers limitations similar to the airborne case. Coordination of personnel and equipment is massive and results in high costs. Furthermore, its limited flexibility to create and define totally new and different scenarios for the students results in reduced situations and intercepts.

The alternative to training in the field is with a simulator using an artificial environment. In the case of airborne EW training, this involves the incorporation of EW into the flight simulators, providing the pilot with simulated EW environments and the resulting display indications. The use of flight simulators has been accepted for many years as a cost-effective tool for pilot training. Of equal or even more significance is that it presents the only method of introducing (under controlled conditions) malfunctions or emergency conditions, thus training the pilot to cope with rare and potentially hazardous circumstances. EW training presents a number of parallels to flight simulation in terms of cost, coordination, and the need to provide training against postulated conditions which cannot be generated in real-life without potentially catastrophic consequences.

The simulation approach allows an instructor to directly monitor and control the EW training exercises. It permits freezing the situation and can provide an "instant replay" capability for highlighting and explaining mistakes. The instructor can set up varieties of scenarios prior to training sessions and can dynamically control and modify the scenarios during the training sessions. Controlling the entire EW environment and coordinating the EW training with mission flight training is a significant advantage to the simulation approach.

One of the more interesting aspects of airborne EW training that can be incorporated only when using the simulation approach involves the simulation of active electronic countermeasure (ECM) equipments and their effect upon hostile weapons systems. These ECM equipments include both noise and deception jammers, and various expendables such as chaff and flares. In field training it is difficult, if not impossible, to employ these ECM techniques and determine their effectiveness against anti-aircraft artillery or surface-to-air missile (SAM) systems. A trainer permits these situations to be simulated and the effectiveness of jamming and maneuvers to be evaluated. The degree to which this simulation is performed can vary greatly from a rather superficial simulation to an extremely detailed model. A superficial treatment would determine only if the proper ECM were selected for the particular threat type and, if so, score a miss. A more detailed simulation would include SAM missile dynamics and the entire guidance command loop, including the guidance computer. The degree of simulation employed in any particular simulator depends upon the overall system requirements. The important point to note is the potential which is possible with an EW simulator.

With the need for EW simulation clearly established, planners are making EW simulation an important requirement for next-generation flight simulators. This paper is not intended to extoll the virtues of EW simulation but rather to explain how this EW aircrew training can be provided in a cost-effective manner with present technology.

GENERAL REQUIREMENTS FOR AN EW AIRCREW TRAINER

To be an effective training tool, there are a number of features which must be incorporated into an EW simulator. First, an accurate modeling of the EW environments postulated for future conflicts is needed. Not only must the emitter signal models possess sufficient flexibility needed to simulate complex signal types, but the number of signals and their tactical usage must be representative of that expected. Next, the onboard EW equipment simulation must be realistic. In those cases where the EW equipment contains analog displays, the various anomalies such as noise, flicker, and fanning must be accurately preserved. In the case of computer-based systems which typically contain alphanumeric displays, the display itself can be duplicated; however, any failure modes of the system such as overloading, misidentification and response times must be accurately duplicated. All major audio and visual cues derived from normal operation and failure operation of the equipment, including their anomalies, must be included in the simulation for adequate training.

Proper generation of the display and operation of the controls is only part of the EW simulation and training problem. Another part involves the instructor and his ability to set up situations and monitor the student's responses. The instructor must first have some convenient and rapid method of inserting and deleting, as well as monitoring and controlling the modes of operation of emitters. Some of these emitters may be attack aircraft, and some method of specifying their initial location and engagement profile is required. In the ground case, emitters may also be mobile; again, it is necessary to specify the position and expected movements. The modes of emitter operation such as searching and tracking and the activation of missile guidance and launches must also be controllable by the instructor. Emitter modes could be automated (canned) to reduce the instructor's burden during a tactical training mission, but should also be manually controllable for specific training exercises.

Another requirement of an EW aircrew trainer is a real-time interface to flight training devices. Learning how to operate the equipment and identify threats is only half of the training objective. The other half is to learn and practice tactical maneuvers and ECM procedures in conjunction with other flight mission activities. Integrating an EW training device with an operational flight trainer may be the only practical means of providing adequate tactical engagement training for our pilots and EWO's.

The interface between the EW simulator and the flight trainer can vary through a wide spectrum, depending on the overall extent of the simulation and training requirements. At a minimum, the EW trainer must receive from the flight trainer computer all real-time flight parameters such as aircraft position, altitude and attitude in order to adequately simulate the relative power and incident angles of simulated radar signals on the

airborne EW antenna system. In addition, the EW trainer must supply to the flight simulator computer such information as chaff salvo drops and other parameters which can affect the weight and balance or lift and drag coefficients of the simulated aircraft.

Finally, a principal requirement of an EW aircrew trainer is flexibility and updateability. The instructor must have the capability of creating, modifying and controlling a wide variety of training exercises and tactical encounters. Ideally, the mechanisms for controlling the simulated environment should be simple and convenient, so that the task of training and qualifying an instructor does not overshadow the student training program. Also, the EW trainer should accommodate updates in EW equipment and EW environments with minimal impact on cost, development time, and minimal delays to training programs.

SOME DESIGN CONSIDERATIONS

There are numerous factors which will affect the design considerations of an EW simulator/trainer system. These design considerations can be grouped into three major categories: the EW environment simulation, the EW equipment simulation, and the instructor facilities for monitoring the student's responses and controlling training exercises.

Simulation of the environment involves a modeling of each emitter, including location and signal characteristics. The degree of simulation and amount of hardware and software required depends heavily upon the type of EW equipment involved, the method in which the EW equipment is being simulated, and degree to which the equipment is being modeled. A simplified, low-cost approach uses "logical" simulation, in which a determination is made as to whether the signal from an emitter is within range and line of sight. If so, the signal is determined to be detected and the appropriate display is generated. Unfortunately, this "logical" approach typically lacks realism and misses important training cues. At the other extreme is a pulse-by-pulse simulation wherein the characteristics of each pulse are modeled in detail. This approach requires excessive hardware and/or software to implement, is very costly and, in some cases, oversimulates the inputs to the simulated EW equipment. Depending upon the specific application, an approach lying somewhere between these two extremes is normally used.

The EW equipment simulation involves understanding, in detail, the operation of the various EW equipment from antenna to display and readout. Consider the antenna portion of an EW system. This may be omnidirectional, scanning, multiple directional, or phased array. The type incorporated in the EW equipment has a significant effect upon the method of simulation. For example, if an omni is employed, then the antenna modeling becomes greatly simplified. In the case of a multiple monopulse DF array, the response of each individual antenna must be considered. In some cases, an azimuth-only simulation may be sufficient; in others, elevation may also be required. If the antennas are circularly polarized, then polarization effects need not be incorporated; if they are linearly polarized, then these effects need to be simulated. Scanning antennas pose a different type of problem.

The receiver simulation involves many of the same tradeoffs as the antennas. For example, the receiver may be wideband and capable of receiving multiple signals simultaneously, or narrowband to select only one. It may be of a scanning type to drive a panoramic display, or tunable to signals of interest. Further, the tuning may be automatic or manual. These various receiver characteristics must be accurately simulated to ensure proper training cues. One example is the narrowband receiver that is used to reduce the environment to a single signal of interest. No receiver possesses the ideal, infinitely sharp skirts in the IF processing section; thus, closely spaced signals may not be separable.

In addition to EW environment and EW equipment simulation, another consideration involves the instructor control and monitoring facilities. This area allows the most freedom for the simulator designer to select different approaches. The ultimate goal is to provide the instructor with the greatest amount of capability in defining scenarios, making dynamic alterations to it as the EW operator is training, and providing the ability to monitor the status of the environment, equipment modes and student responses. Probably the largest constraint is cost. There are graphic devices which, when coupled with the appropriate software can display all types of display symbology. Although there is great flexibility in this area and the potential is nearly unlimited, it offers the designer one of the most significant design challenges to provide the maximum amount of information and control capability with whatever cost constraints have been imposed.

VARIOUS DESIGN APPROACHES

There are a number of methods by which an EW simulator/trainer can be implemented. These range from various methods of signal generation and the use of actual EW equipment to a total software modeling of the environment and the equipment itself. This latter method, which is employed exclusively in flight simulators, has not been employed for EW simulation until recently.

Possibly the biggest disadvantage to generating live signals and injecting them into the EW system is the cost and complexity of the signal generation hardware required. In the event the EW system possesses limited recognition logic, these signals can be generated with a minimum of complexity. However, in most modern wideband EW systems, like the radar warning receiver (RWR), more and more use is being made of all modulation parameters including amplitude, scan, pulse frequency modulation (PFM) type, and pulse group spacings. As the RWR makes more use of these parameters, more care must be taken to generate precise replicas of the actual signal to ensure proper EW system performance. Although certainly possible, the cost of generating and mixing these parameters with the required modulations and accuracy makes this method less and less desirable from a cost standpoint.

The software modeling approach to EW simulation provides the greatest amount of flexibility and growth potential since virtually any EW system under any conditions can be simulated by the addition of more software. This type of simulation requires the initial investment of a computer, memory and some peripherals and display driving hardware. Once this investment has been made, it can be expanded via additional software at a relatively gradual slope. It should be noted that the hardware signal generation approach would also require a computer or intelligent processor to control the real-time signal modulation and gating.

In addition to cost, there are a number of other benefits inherent in the software modeling approach. These include increased realism, flexibility, repeatability and system reliability and maintainability. The increased realism is achieved because all factors can be modeled to whatever extent is necessary to produce displays corresponding to real life. Nearly every EW system, whether analog or computer-based, has some anomalies. In some cases, these provide the EW operator with additional information that can assist in identifying threat signals. Whatever the case or result, the EW operator will face these effects in a combat situation and must be trained to deal with them. In terms of reliability and maintainability, the software modeling approach uses far fewer components, and those components are primarily off-the-shelf commercial computer parts.

Another advantage of the software approach involves the ability of the instructor to induce artificial EW equipment failures and monitor the student's reaction. Since the EW system is modeled in software, this feature is easily incorporated. Finally, the remaining simulator requirements of dense and complex environment generation, as well as instructor flexibility, can be readily accommodated.

Possibly the most difficult portion of the software modeling approach involves the signal analysis and display portion of the equipment. In somes cases, the analysis portion of the equipment is rather rudimentary involving pulse repetition frequency (PRF) filters for pulsed signals or manually tuned oscillators for CW signals. In these types of systems the signal processing simulation is straightforward, but proper generation of the displays and audio can become quite involved. These systems possessing minimal analysis and recognition capability rely heavily upon operator interpretation of the various subtleties and anomalies in the displays. Thus, it is imperative that the modeling be accurate in terms of tones and warbles on the audio and flicker and jitter on the displays.

Many of the newer EW systems incorporate computers into the equipment and utilize extensive software analysis to perform the actual signal recognition and identification functions. Since the analysis is performed by a computer, the displays associated with this type of system are typically "synthetic" with only the results of the analysis being displayed. In many cases, the display is in the form of alphanumerics graphically depicting the signal environment or tabular readouts. The simulation of the processing is the most difficult task in this type of system, since it is mandatory that the operator be presented with the results which would have been obtained with the actual equipment. In those environments where the equipment might false-alarm and report a "phantom" signal, the simulator must "fail" in the same manner. Likewise, the simulator must not detect those signals which the actual EW system might miss due to overload or peculiar signal conditions.

A SUCCESSFUL LOW-COST SOFTWARE SIMULATION APPROACH

Applied Technology has recently delivered and installed two EW aircrew trainers designated

RSI (RHAW Simulator Interface) for pilot training on an analog radar warning system. For the previously stated reasons of realism, fault modeling and cost, these simulators employ a software simulation approach and use only the displays and indicators of the EW system. The majority of the simulator logic resides in software, and only minimal interface circuitry is required to drive the displays and generate the real-time audio.

The simulator design goal was to accurately model all normal and several failure modes of operation of this equipment, to provide a realistic simulation of a flexible, interactive EW environment, and to provide a number of instructor control and monitoring functions. The hardware used to satisfy these requirements consists of four elements:

- General-purpose microprogrammable mini-computer
- General-purpose CRT/keyboard
- General-purpose teletype, hardcopy, and data entry terminal
- Special purpose, ATI-built instructor display and control chassis with repeater displays and controls of the EW simulated system instruments, with EW emitter control switches and indicators, and with trainer controls and status indicators.

The radar warning system that is simulated consists of a four-channel monopulse direction finding system. There are four directional antennas located 90 degrees apart around the aircraft, and a receiver located near each antenna. The receiver contains crystal detectors and compression video amplifiers. Incoming pulses from an emitter which are strong enough to be detected are then amplified. The outputs of the video amplifiers are routed to an analyzer where the four quadrants are summed and thresholded. Whenever this threshold is crossed, a synthetic pulse is generated and applied to a bank of PRF filters which classify the pulse for signal type. Depending upon which filter passes the pulse, a "strobe code" is generated. The four amplitudes from the four receiver channels are applied to a CRT indicator which vectorially combines these signals and draws a strobe. The vector addition of the four channels causes the angle at which the strobe is drawn to be an approximation of the direction-of-arrival (DOA) of the signal and the length to be representative of the signal strength. The strobe code from the PRF filter bank causes a dotted, dashed, or solid trace to be drawn. Further, each strobe is applied to audio circuitry for injection into the intercom, and each PRF filter output is applied to an associated lamp driver to light a legend on a threat display unit (TDU). The end result of this processing is to supply the pilot (or EWO) with a CRT display and a billboard legend. The CRT is a polar display with coded strobes depicting threat type and their angle and length depicting direction-of-arrival and received power, respectively. The billboard displays those signal types which are presently being received as well as providing the operator some control capability over the system.

In addition to the radar warning system, there is an associated guidance receiver which intercepts from the ground certain command signals which are directed to a surface-to-air missile. This receiver detects these signals, performs a logical analysis to determine the status of this command, and outputs various pertinent data to the RWR analyzer. The analyzer uses this data to highlight certain signals on the indicator, light appropriate legends on the TDU, and issue audio alert tones into the pilot's intercom.

The simulation of the radar warning receiver and guidance receiver is primarily accomplished by software with minimal hardware. Using only the operational CRT display and TDU, plus a CRT driver card and a general - purpose pulse generator card, all other operational hardware was modeled in software. The quadrant antenna spatial gain characteristics, the receiver transfer functions, and all the internal analyzer logic was modeled in real-time software. The CRT signals and audio tones produced by this simulation technique turned out to be highly realistic with respect to visual cue accuracy, correlation between audio and visual cues, and ability to repeat most of the operational equipment anomalies.

The simulated EW environment used in the RSI is designed to handle 16 simultaneously active, yet independently controllable, threat emitters. A table of radar parameters and positional information is assigned to each simulated emitter. Some of the threat radars which can generate multiple emissions, such as dual-beam target tracking radars and SAM tracking radars with associated guidance signals, only require a single emitter by the simulator. Thus, all 16 emitters can be assigned to different targets. At any moment in a training session a tactical scenario consisting of 16 simultaneous emitters is quite adequate. However, over the entire training session many sets of tactical scenarios are required. The RSI provides four scenarios as a standard feature which is easily expandable. With four scenarios containing 16 emitters each, the RSI provides

storage and simulation of 64 unique threat emitters. Each scenario is assigned a geographic location within the gaming area of the flight simulator. The 16 emitters which can be assigned to a scenario can be positioned either inside or outside the scenario's geographic boundaries, provided the emitter position is somewhere within the overall gaming area. Scenarios can be of a different size, and overlapping is permitted. When the instructor selects the "tactical situation display" on his CRT terminal, the current scenario of emitters is used for display. Scenarios are automatically switched and updated on the "tactical situation display" whenever the simulated aircraft flies from one scenario boundary into another. To account for overlapping scenarios, each scenario is assigned a priority number. The highest priority scenario is selected for display if a conflict exists.

In conjunction with instructor display functions, the emitters of the currently active scenario are assigned to the control switch on the instructor display and control chassis. For each emitter, the instructor can select either an automatic or manual mode. In the automatic mode, four range rings for each emitter are preprogrammed. The outermost ring represents the maximum search range for the emitter; the next one represents the tracking range. As the aircraft passes through the first range ring, the emitter is automatically activated and placed in the search mode. When it passes into the next ring, it is placed in the track mode. The last two range rings are used for surface-to-air missile (SAM) sites. When the third boundary is crossed, the guidance signal is activated and placed in a non-launch condition. Finally, when the last boundary is crossed, the missile is launched and the appropriate missile launch condition is generated. In addition to this automatic emitter mode control, the instructor can select the manual mode of operation. In this mode, the instructor can override the automatic emitter mode and select any of the modes (search, track, missile active, or launch conditions) desired. With this capability, the instructor can simulate an optical tracking site.

The RSI simulator has two basic modes of operation: a mode integrated with the flight simulator and a stand-alone mode. In the integrated mode, the simulator receives the dynamically updated position and attitude of the aircraft from the flight simulator and uses this data in subsequent computations for determining the appropriate display and audio indications. Measurement of the aircraft parameters and computation of ranges and received powers is made ten times per second to permit smoothly varying displays. In this mode, the pilot sees and hears the appropriate indications as a function of his flight path. Emitters move in angle on the indicator, and their relative powers vary appropriately. In addition, the simulator provides automatic threat status changes as a function of slant range and line of sight.

The stand-alone mode is used primarily for classroom training with one or more students. In this mode, the aircraft can be flown by the instructor via typed commands on the CRT terminal to control altitude, ground speed, and heading. Alternatively, a prerecorded tape can be used from a previously simulated mission. In either case, the controls on the threat display unit of the EW system are fully operative and can be used to demonstrate pertinent EW system features. Further, the system can be placed in a "freeze" mode or backed up in time to demonstrate critical display characteristics or signal parameters.

The CRT terminal and instructor control panel operates in both the integrated and stand-alone modes, providing the primary means for the instructor to control the RSI simulator. It provides a comprehensive set of commands to enable alteration and monitoring of emitter scenarios and emitter parameters, as well as to monitor, insert, or delete simulated equipment malfunctions. The CRT monitor provides five separate pages of information to enable effective monitoring of the exercise status. The contents of each page are summarized below:

- First is an index page, which indicates which pages are available for viewing and the commands required to call each one.
- Second is the emitter scenario page, which displays detailed status on each of the scenarios. On it are the scenario coordinates and scaling factors. Further, it contains summary information such as location and type of each of the emitters assigned to each scenario.
- Third is the emitter parameter page, which contains all of the detailed information on each emitter. Contained on this page is the transmission power, RF frequency, PRF, pulsewidth, scan characteristics, and other parameters defining each simulated threat radar. Further, it contains the ranges at which the signal changes modes (i.e., search to track) should the automatic mode change be selected for that emitter.

- The fourth page contains the tactical situation display (one for each of the scenarios). The left half of this page contains summary information on the scenario coordinates, site and emitter types. Also, it contains current aircraft heading, speed and altitude, which are automatically updated. On the right half of the page is a graphical representation of the tactical situation. This tactical situation display is the page normally selected during the training session; it is used to indicate graphically to the instructor the aircraft location with respect to the emitters so that the instructor can manually activate and deactivate sites and attempt to confuse or lure the pilot into lethal situations.

- Fifth is the malfunction page, which enables the instructor to determine the status of simulated EW system malfunctions. Each malfunction can be independently turned on or off at any time during the training session to test the reactions of the pilot.

Although the various modes of operation and instructor flexibility are important, it is the realism of the simulator that makes it truly unique. This realism is due primarily to the detailed modeling of the EW system anomalies. These anomalies appear in both audio and visual indications. Each EW system has its own set of anomalies, and those programmed in the RSI software are designed for the particular radar warning system being simulated.

The most recognized of these anomalies is the "fanning effect" of strobes from a single emitter. Briefly, this effect is due to antenna patterns, receiver transfer functions, pulse filter characteristics and the vector addition used to compute direction-of-arrival. The net result is that amplitude variations of a received signal result in apparent angle changes. Thus, any emitter exhibiting amplitude modulation due to scanning has some angular fanning on the radar warning display. Furthermore, since the antennas are not perfectly circularly polarized, but are slightly elliptical, polarization effects cause an effective amplitude modulation to be received and, hence, fanning to be produced.

These effects are not particularly detrimental to the effectiveness of the radar warning system, and in many cases are used to advantage. For example, there is one threat signal which employs two beams to locate the target in azimuth and elevation. The two beams are not synchronized and hence they tend to "walk through" each other. During these walkthrough periods, a greater amount of energy is received and the fanning decreases. Between walkthrough periods, the fanning increases and a lesser amount of energy is received. In the case of another dual-beam threat signal, the beams are synchronized and this additional fanning effect is not observed. A trained pilot can quite readily distinguish these two signals and make a precise identification of the threat emitters over and above that provided by the analysis logic in the warning system.

In another case, there are two different threat signals in the same RF frequency band and with the same PRF characteristics. The only distinguishing characteristic between them is their scan characteristic. One of the signals operates in a lobe-on-receive-only (LORO) mode, and this is extremely constant in terms of amplitude variation. The other signal operates in a conical scan mode and therefore exhibits a sinusoidal amplitude modulation. Although these modulations are small and are difficult to see as strobe length changes on the azimuth indicator, the fanning effects cause this modulation to be highlighted and, hence, quite readily discerned by a trained pilot.

The RSI software incorporates these effects and has most successfully passed extreme scrutiny from experienced test pilots intimately familiar with the radar warning system. Briefly, the algorithms which simulate these effects utilize scan type, range, beamwidths, and other pertinent factors to describe, on a pulse-to-pulse basis, the strobe display that would be generated.

The RSI software is organized as two major program loops, each operating at a different speed. The outer loop, executed at a rate of ten times per second, contains the major simulation programs. When it is entered, the aircraft coordinates are entered into the processor and scaled. First, the elements of an Euler matrix are computed and used to perform an inertial-to-body axis transformation. Next, the range and power from each emitter are calculated. Also, the angles the incident energy makes with each antenna are computed. A power calculation is made, and the appropriate antenna gain for that azimuth and elevation is used. Next, the receiver transfer characteristics are modeled, and finally a threshold check is made to determine if the received pulse was above the receiver threshold. If so, additional modeling to determine strobe code and fanning characteristics is made. These characteristics are then used for the next one-tenth second until a new computation is made.

The inner loop operates on a pulse-to-pulse basis and is implemented entirely in microcode. Briefly, it is activated by an interrupt at the conclusion of each strobe generation. It determines which pulse is eligible next for display, addresses through the appropriate tables to locate the next angle, amplitude and strobe code and outputs it to the interface circuitry which draws the next strobe. The microcode program requires approximately 20 microseconds to execute. Since a strobe requires 100 microseconds to draw, it is impossible to saturate the simulator regardless of pulse density or number of emitters. At most, it requires 20 percent of the CPU time. Alternate designs have hardware complexities orders of magnitude greater. The total hardware for this approach, without the deflection amplifiers, is physically located on two I/O board and requires less than 100 integrated circuits.

FUTURE TRAINING DEVICE REQUIREMENTS AND SOLUTIONS

Looking into the future, it is obvious that the EW environment will increase in complexity and density. Aircraft EW equipment will also increase in complexity to keep pace with the growing environment. A look at the ALR-67 and other radar warning and power management systems illustrates this increasing complexity. These new-generation onboard EW systems must interface with other aircraft avionic systems, control active ECM equipment and, in some cases, interface to weapon delivery systems. With the expansion in the use of processors and microprocessors, the tasks performed by the EW systems are taking quantum jumps. The next generation of EW systems will include IFM's, laser intercept systems, and new onboard jamming systems. All this points to an increased burden on our pilots and EWO's. The only solution for these EW personnel to acquire and maintain proficiency is through training, and the only practical and cost-effective means of training is through ground-based EW equipment trainers.

EW simulators are still at the formative stage and a number of significant advances can be expected in the future. Applied Technology believes the RSI simulator has demonstrated two such advances. The first is in the area of realism. The algorithms employed in this simulator provide a detailed modeling of the environment as well as the equipment. The end result is a display and audio tones which have undergone the final test of experience. The pilots who have seen and heard the simulator believe it to be a most accurate representation of the real thing. Side-by-side comparisons with signal generators and the actual EW system show the simulator to be far superior to even an untrained eye let alone one of experience. Second, the use of microprogramming to eliminate pulse and scan generators has made a most dramatic reduction in system complexity and resultant cost. Further, it allows a far greater degree of flexibility to incorporate new systems and new capabilities.

Next-generation EW simulators must include these new capabilities and must meet the realism standards which are within the realm of state-of-the-art technology. The requirements are real and there is no reason they cannot be met in a cost-effective manner. Further, these simulators should include SAM missile dynamics and provide automatic scoring of the pilot's reactions. Flight simulators can be used to determine the aerodynamic effects when new ordnance or equipment is carried or modifications to the airframe are made. The flight simulators have modeled the aerodynamic effects so completely that these alterations are tested on the simulator prior to being flown. With sufficient realism, similar tests could be made with tomorrow's EW simulator to determine the effectivity of new maneuvers, tactics, and equipment.

We believe that EW expertise is the key to meeting the EW simulation requirements of the future. Realism is the key to effective training, and an intimate understanding of the equipment is vital to developing a realistic simulation.

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SUITABILITY-FOR-TRAINING EVALUATION OF THE CH-47 FLIGHT SIMULATOR

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BACKGROUND

Although many improvements have been made in the conduct of US Army helicopter flight training, the most important part of the student's instruction is still performed in an aircraft under the direct supervision of an instructor pilot. This method is extremely costly in terms of time required on the flight line by both student and instructor and in terms of flying hour costs in today's sophisticated aircraft.

These costs became more apparent during the late 1960's when the Army experienced a rapid expansion of its aviation capability. The huge increase in the cost of aviation training which accompanied this period of expansion clearly indicated the need for economical synthetic flight training systems which could reduce the requirement for use of operational helicopters.

To fulfill this need, the Army approved a Qualitative Materiel Requirement for development of a synthetic flight training system in July 1967. Eventually, a contract was awarded in June 1973 for the construction of a flight simulator of the CH-47C Chinook aircraft.

The operational test of the CH47FS began in January 1977 and was completed in August 1977. The training effectiveness studies were conducted by the US Army Aviation Board and the US Army Research Institute Field Unit at Fort Rucker, Alabama.

DESCRIPTION

The CH-47 flight simulator (CH47FS) is a ground-based flight simulator designed to provide training on CH-47C helicopter cockpit procedures, aircraft control, contact maneuvers, emergency procedures, sling load, confined area operations, and instrument flight procedures.

The simulator system consists of the following major subsystems:

- o Flight compartment consisting of:

  Trainee station for pilot and copilot (cockpit)

  Instructor/operator station

- o Six-degree-of-freedom cockpit motion system.

- o Visual simulation system consisting of:

  Camera-model image generation system

  Synthetic terrain and ground symbol generator

  Infinity-image display systems mounted on cockpit.

- o Digital computation system and associated software.

These subsystems will be described in the subsequent paragraphs.

FLIGHT COMPARTMENT

The operational flight trainer's flight compartment interior contains a replica of the pilot's and copilot's positions, the instructor/operator's station, and an observer's position. A doorway through the rear bulkhead provides for entry into the compartment.

The trainee station is located in the forward portion of the flight compartment and is a replica of the pilot's and copilot's positions forward of their seat backs. The controls, indicators, and panels operate and have the same appearance as those in the aircraft. The aft portion of the center console contains the instructor pilot/trainee problem control panel. The trainees' seats are vibrated individually to simulate the continuous and periodic oscillations and vibrations experienced by the crew during normal and emergency flight conditions and maneuvers, including vibrations representing progressive malfunctions. Four loudspeakers provide aural cue sounds with characteristics of location, frequency, and amplitude simulated within limits of safety.

The instructor station is located in the instructor area, aft of the cockpit, in the flight compartment. It provides information and controls with which the instructor can effectively monitor and evaluate student performance and control the training problem. The controls are located on a sloping control

panel below two cathode-ray tube (CRT) displays which are mounted side by side with their longer display surface dimension vertical. The instructor is also able to operate from either trainee station by using the problem control panel on the center console.

MOTION SUBSYSTEM

The flight compartment is mounted on a six-degree-of-freedom motion subsystem consisting of a moving platform assembly driven and supported from below by six identical 48-inch hydraulic actuators. Simulation includes the motion due to changes in aircraft attitude as a result of flight control and the rotor operation, rough air and wind, changes in aircraft weight and center of gravity, as well as effects of buffet, blade stall, blade imbalance, blades out of track, and touchdown impact.

The simulation program causes the motion subsystem to respond to aerodynamic forces and moments within the mechanical limits of the system. All motions except pitch are imperceptibly washed out to the neutral position after the computed accelerations have reached zero. Pitch attitude is maintained as necessary to simulate sustained longitudinal acceleration cues. Acceleration onset cues are scaled as large as possible to fully utilize the motion capabilities of each degree of freedom.

VISUAL SUBSYSTEM

The visual subsystem is a camera-model system which provides a full color television image in the forward-looking window displays. The chin window displays are provided by a synthetic terrain generator.

The camera-model visual system consists of a 24 x 56 foot three-dimensional terrain model viewed by a television camera and optical probe mounted on a movable gantry. Servomechanisms on the gantry position the camera and probe in accordance with the position and attitude of the simulated aircraft. The model board is mounted vertically to minimize floor space requirements and has scales of 1:400 and 1:1500. The 1:400 scale model is a replica of the east side of Hanchey Army Heliport and represents an area approximately 0.5 x 1.6 nautical miles (nm). It simulates the detail needed for taxi work and low-altitude hovering. The 1:1500 scale board contains Goldberg stagefield and the surrounding terrain as would be seen in southeast Alabama during spring. The gaming area of the 1:1500 scale model represents 5.75 x 11.75 nm and is used for the training of tasks requiring a larger geographical area such as general airwork, contact maneuvers, pinnacle, confined area, and sling load operations. A special effects generator provides sky, cloud, haze, and limited visibility effects into the displayed scene under the control of the instructor. Day, dusk, and night-light conditions are also simulated.

The synthetic terrain generator used for the pilot's and copilot's chin window displays provide a special ground symbol and a terrain representation consisting of a regular checkerboard pattern of alternating 7-foot green and brown squares, in correct perspective for each trainee eyepoint. These squares form a larger square pattern 56 squares on a side with continuous green terrain beyond the squares and white sky beyond the horizon. When the simulated helicopter is within a 0.7 nautical mile radius of a symbol location, and between 10 and 200 feet above the ground reference plane, the terrain pattern is automatically computed and displayed; beyond this range the synthetic terrain display is either in or above clouds.

The visual images generated by the camera-model and synthetic terrain systems are displayed via closed-circuit television to both the pilot and copilot simultaneously in their forward and chin window displays. The entire display is collimated by a beam splitter and curved mirror. The total field of view visible by movement of the head is approximately 48 degrees horizontal and 36 degrees vertical on the forward windows, and 45 degrees down and 25 degrees outboard in the chin windows.

COMPUTATION SUBSYSTEM

The computation subsystem consists of a dual PDP 11/45 computer with associated memory and peripheral units. The operational software consists of an executive program and real-time simulation programs. The real-time simulation programs, in conjunction with the appropriate hardware, provide simulation of flight performance, power plants and engine-related systems, aircraft accessory systems, radio communication and navigation equipment, atmospheric conditions, flight control systems, and malfunctions. The executive program includes computer diagnostics, a daily operational readiness check program, and a test exercise program.

EVALUATION

GENERAL METHOD

The training effectiveness of the CH47FS was evaluated in two studies: one to determine the transfer of training between the simulator and the aircraft in an institutional setting and another to determine its effectiveness in maintaining or increasing flying

skills in an operational setting. Study I was of classical two group training design using aviators undergoing transition training to the CH-47. Study II assessed the training benefits of periodic training of operational CH-47 aviators in the CH47FS.

STUDY I

INSTITUTIONAL TRAINING

SUBJECTS

The experimental group consisted of 24 student aviators selected four at a time from each of the six CH-47 transition classes that participated in the study. The experimental aviators were selected on the basis of two screening tests as well as recent and total flight experience to be equivalent to the remainder of the class. Those 35 Army aviators in the six classes not chosen as experimental subjects were the control group aviators.

INSTRUCTOR PILOTS

In preparation of these training studies, six CH-47 instructor pilots (IPs) spent three weeks learning to operate the simulator and practicing teaching in the device. Four of the IPs were from the US Army Aviation Center and were engaged in teaching CH-47 transition courses. Two of the IPs were from Forces Command (FORSCOM) units and were engaged in combat readiness flying (CRF) training.

INDEPENDENT VARIABLE

The independent variable in this experiment was the use of the CH47FS in the course of instruction (COI) of CH-47 transition training. The control group was trained to fly the CH-47 in a COI developed over several years with a nominal flying time of 30 hours (US Army, 1975). The COI is split into two phases of approximately 15 hours each; a basic phase and an advanced phase. In the basic phase the following procedures and maneuvers are taught: pre- and postflight inspections, cockpit procedures, taxiing, hovering, various takeoff and landing maneuvers, general airwork, and emergency procedures. The advanced phase includes training in confined area and pinnacle operations, external and internal load operations, slope operations, water operations, and emergency procedures. Between the basic and advanced phases there is a checkride and, at the end of the advanced stage, there is the final aircraft qualification checkride.

The COI used by the experimental group was the same as that used by the control group except that the instruction was conducted in the CH47FS rather than in the aircraft. Due to design limitations, internal load, slope and water operations could not be performed in the simulator. The checkride given between phases was accomplished in the simulator and again in the aircraft. This basic phase checkride was the first time the experimental aviators had flown in the CH-47 aircraft. The advanced phase of training was then conducted in the simulator and the final checkride given in the simulator. This was followed by an identical checkride in the aircraft. Those maneuvers not performed satisfactorily on the last checkride were then trained in the aircraft and the CH-47 qualification checkride given. Thus, the experimental group took three more checkrides than the control group.

PERFORMANCE MEASURES

The CH-47 transition course was divided into 32 separate and gradable tasks or maneuvers. During daily training, each time a maneuver was performed, the IP recorded that performance on a daily grade sheet designed for this study. For each maneuver the IP recorded an evaluation of that maneuver on a twelve point scale, the time spent on the maneuver, and a rating of subtasks associated with the maneuver.

The twelve point scale used to evaluate each maneuver was based on a scale by Reid (1975). The rating scale actually encompassed thirteen points since a maneuver demonstrated by the IP was coded as a zero. Varying degrees of "unsatisfactory" performance were rated one through three, "fair" was rated four through six, "good" was rated seven through nine, and "excellent" was rated ten through twelve. Performance level six was considered the minimal acceptable level of skill and was the criterion level towards which training was aimed.

Thirty of the 32 graded maneuvers were also divided into subtasks and the performance of these subtasks was evaluated. Each subtask was rated on the basis of performance being (1) near perfect, (2) error present but within acceptable standards, (3) error present and beyond acceptable standards. The acceptable standards were defined by the Flight Training Guide and were well known to the IPs and students.

CUMULATIVE TRANSFER EFFECTIVENESS RATIOS

The most important descriptive statistic for the evaluation of the training effectiveness of the CH47FS was the cumulative transfer effectiveness ratio (CTER). The CTER, as described by Roscoe (1971, 1972, 1973), is a measure of the savings realized in learning to operate an aircraft by first training

in a training device. The formula for the CTER based on training trials is:

$$\frac{\text{A/C trials control group} - \text{A/C trials exp group}}{\text{Simulator trials exp group}}$$

CTERs were calculated on the basis of trials for each individual maneuver in the COI. A CTER is a measure of the training efficiency of a training device. A ratio of 1.0 indicates the training device is as efficient as the actual device, a ratio greater than 1.0 indicates the training device is more efficient, and a ratio of less than 1.0 indicates that the training device is less efficient.

LEARNING CURVES

Learning curves are graphical presentations of changes in skill that occur with practice or overtime. The learning curves in this paper relate the skills of the aviators on each maneuver (as measured by their IPs on the twelve-point scale) to the number of times that maneuver was demonstrated or performed. One set of learning curves is presented to illustrate the progress on each maneuver by the control group that was trained only in the CH-47 aircraft and another set to show the progress of the experimental group that trained in both the simulator and the aircraft. Each maneuver's graph has three curves on it. The middle of the three curves represents the average performance of the group and the enveloping curves represent approximately plus and minus one standard deviation. The plots are based on the 16th, 50th, and 84th percentiles of the groups. Therefore, the extreme curves encompass, in both performance level and trials, the reasonable extremes of the classes.

OPERATIONAL PROCEDURES

Each class of approximately twelve aviators reported to Fort Rucker several days before the start of flight training for administrative purposes and to attend ground school in preparation for the flight training.

At the start of flight training both groups spent half a day together in ground school and split the second half day for separate flight training activities. The control group underwent flight training in the CH-47 aircraft according to the program set out in the Flight Training Guide. During this training the IPs used the daily grade sheets and recorded for each maneuver the students' performance on each attempt, performance on the subtasks, and the time spent on the maneuver. The IPs were instructed to train the students to a performance level of six on the twelve point scale. This level of skill was considered the criterion for passing all checkrides and an acceptable skill level from which to continue training after completing the course. However, training was rarely stopped at this proficiency level despite instructions, and IPs would train to levels eight to ten if there was time to do so. At the completion of advanced training, an aircraft qualification checkride was administered and upon passing it the aviator became a qualified CH-47 pilot.

The four students from each class selected for the experimental group did not begin their flight training in the CH-47 aircraft; they began training in the CH47FS. The IPs training them in the simulator followed the same Flight Training Guide, taught the same maneuvers in the same order and to the same criterion level of performance. As was the case with the control group, the IPs teaching the experimental group recorded performance level and practice time for every maneuver performed on the daily grade sheets. The IPs were instructed to train all basic maneuvers to skill level six, the criterion level, in the simulator or until it was obvious that a student would not reach this level of performance in a reasonable amount of time. At the completion of training the basic phase maneuvers in the simulator, the students were given the basic phase checkride in the CH-47 aircraft. Unlike the control group requirement, the checkride did not have to be passed. Following the basic phase checkride in the aircraft the experimental group returned to the CH47FS and continued training on the advanced phase maneuvers. Upon completion of this phase of training, another checkride, similar to the aircraft qualification checkride, was given in the aircraft. At this stage, training in the simulator was stopped and training began in the aircraft. The aircraft training was intended to teach those maneuvers that could not be taught in the simulator and those maneuvers that each subject had not passed in the last aircraft checkride. As will be discussed later, considerably more training was usually given. Training in the CH-47 was followed by the final aircraft qualification checkride in the aircraft. Performance and time data were also collected throughout this last phase of training.

RESULTS AND DISCUSSION

CUMULATIVE TRANSFER EFFECTIVNESS RATIOS

The CTERs for each maneuver taught in both the simulator and the aircraft appear in Table 1. The table presents CTERs calculated from the median number of trials spent training in the simulator and the median number of trials to proficiency level eight spent training in the aircraft.

TABLE 1

CUMULATIVE TRANSFER EFFECTIVENESS RATIO (CTER) BY MANEUVER FROM THE CH47FS TO THE CH-47 AIRCRAFT

Maneuver	CTER Trials to Criterion
General Airwork	1.00
Cockpit Runup	1.50
Four-Wheel Taxi	2.80
Two-Wheel Taxi	1.00
Takeoff to Hover	.63
Hovering Flight	.79
Landing from Hover	.69
Normal Takeoff	.75
Traffic Pattern	.61
Deceleration	1.25
SAS Off Flight	1.33
Normal Approach	.53
Maximum Takeoff	1.25
Steep Approach	1.00
Shallow Approach	.58
Confined Area Recon	1.00
Confined Area Approach	.75
Confined Area Takeoff	.50
External Load Briefing	.67
External Load Takeoff	.50
External Load Approach	.50
Pinnacle Recon	.50
Pinnacle Approach	.00
Pinnacle Takeoff	.33

LEARNING CURVES

Learning curves of maneuvers that were taught in both the simulator and the aircraft are presented in Figures 1 through 6. To represent continuity of training, and learning curves of the experimental group in the simulator and the aircraft are presented on the same graph. For ease of comparison, the learning curves of the control group in the aircraft are presented directly below the experimental group's curves for each maneuver.

OVERTRAINING

One of the factors that makes the interpretation of the CTERs in Table 1 difficult is overtraining. Overtraining occurred when trials and time was spent in training an aviator to perform a maneuver at a skill level greater than level six, the criterion performance level. The following examples will illustrate the effects overtraining can have on CTERs.

Consider a hypothetical maneuver that is properly trained to a criterion in both devices and that transfers perfectly from the simulator to the aircraft. The CTER should be 1.0. Assume that it requires 15 trials to learn in the aircraft, 15 trials to learn in the simulator, and after simulator training requires no further training in the aircraft. Putting these figures into the equation:

$$\text{CTER} = \frac{\text{A/C trials cont grp} - \text{A/C trials exp grp}}{\text{Simulator trials exp grp}}$$

$$\text{CTER} = \frac{15 - 0}{15}$$

$$\text{CTER} = 1.$$

As expected, the CTER indicates that the simulator is as good a trainer as is the aircraft.

Given, for example, overtraining of 5 trials in both devices:

$$\text{CTER} = \frac{20 - 5}{20}$$

$$\text{CTER} = 0.75$$

The resulting CTER gives the erroneous impression that the simulator is not as good a trainer as is the aircraft. This is typical of the CTERs reported in Table 1. The usual case was to overtrain in both devices as can be seen from the learning curves.

The CTERs were calculated on the basis of total number of trials in the simulator since it must be presumed that any overtraining here was transferred to the aircraft. The trials counted in the aircraft training were only those needed to reach criterion. The last example recalculated this way:

$$\text{CTER} = \frac{15 - 0}{20}$$

$$\text{CTER} = 0.75$$

This again gives the impression that the simulator is not as good a training device as is the aircraft.

In an earlier report (McGaugh & Holman, 1977) these CTER data were presented using a criterion performance level of six, the level the IPs were requested to use in training as the criterion to stop training on a particular maneuver. In this report the CTER data presented in Figure 1 are calculated on the basis of a criterion performance level of eight. All of the maneuvers were trained to a median level of at least eight in the aircraft and using this criterion makes the CTERs more typical of what actually occurs in training.

The change in criterion decreased the CTERs of five of the 24 maneuvers and increased the CTERs of 13 of the 24 maneuvers.

The following maneuvers were selected for discussion as typifying the various patterns of transfer from very good to poor.

GENERAL AIRWORK

General Airwork included a number of specific maneuvers such as climbs, descents, and turns. This skill was judged only once per training session and was judged almost every session. Consequently, training on this maneuver exceeded criterion. It was usually rated while flying between stagefields or to other training areas in either the simulator or aircraft. As can be seen by the learning curves in Figure 1, General Airwork was overtrained in both the simulator and the aircraft. The overtraining makes it difficult to interpret the CTER for this maneuver. On a trials to criterion basis, the CTER is 1.0. Had it not been for the unavoidable overtraining, the CTER would probably have been slightly higher than 1.0.

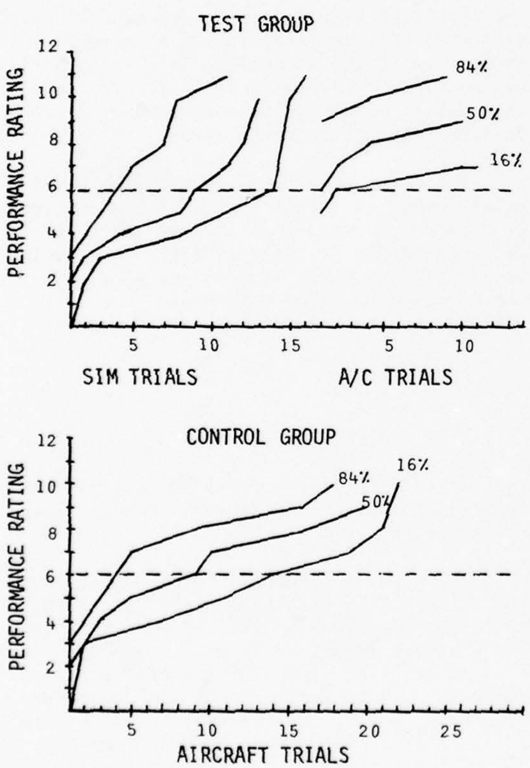

Figure 1. General Airwork

COCKPIT RUNUP

The trials to criterion CTER is 1.5. This CTER and the learning curves (Figure 2) indicate that this maneuver was learned more efficiently in the simulator than in the aircraft. It is often the case that when the learning task is procedural in nature a training device provides a more effective learning environment than that provided by the actual device.

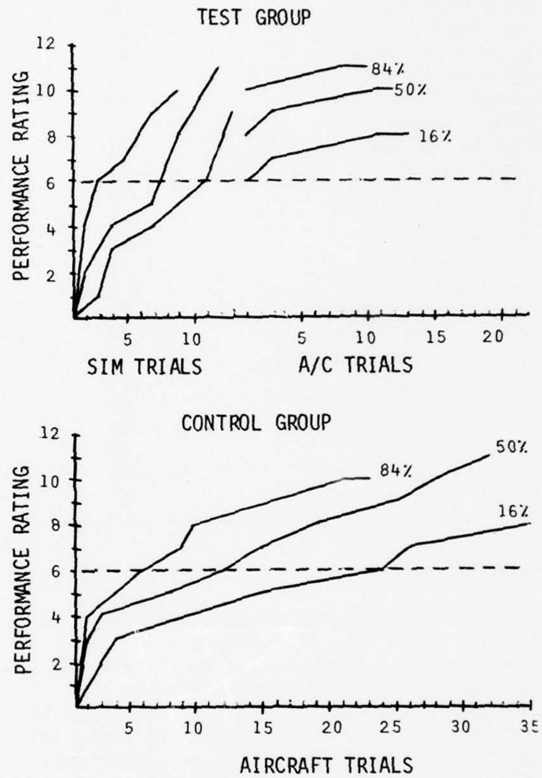

Figure 2. Cockpit Runup

FOUR-WHEEL TAXI

The learning curves for Four-Wheel Taxi (Figure 3) show that this maneuver was quickly learned in the simulator and that this training transferred well to the aircraft. The CTER is 2.8. Since there was little overtraining in the simulator on this maneuver, the trials to criterion CTER accurately reflects the effectiveness of the trainer. A CTER greater than 1.0 indicates that Four-Wheel Taxiing is better trained in the simulator than in the aircraft. As in the case of General Airwork, this maneuver was done frequently in the aircraft as a matter of necessity even after training could have been terminated.

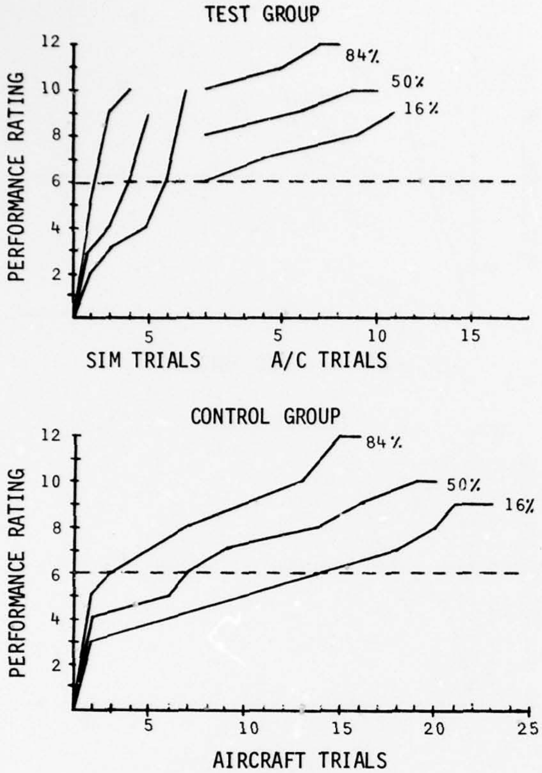

Figure 3. Four-Wheel Taxi

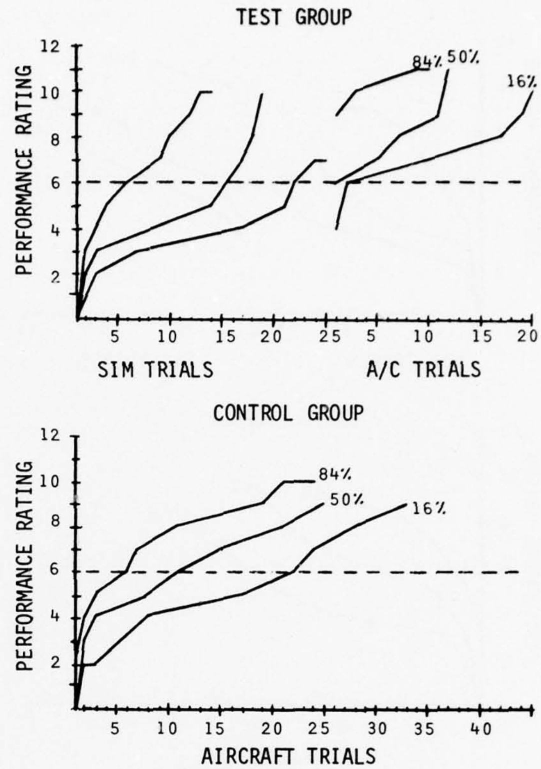

Figure 4. *Hovering Flight*

HOVERING FLIGHT

The hovering maneuvers were among the most difficult to perform in the simulator. Training on them transferred to the aircraft with less efficiency than many other maneuvers. The learning curves in Figure 4 clearly illustrate this point and are typical of learning curves generated by many training devices. The simulator group required more trials than the aircraft group to reach median criterion performance level six (15 trials vs 6) in their respective devices. When starting training in the aircraft, the performance of the simulator group dropped well below its rating established at the end of simulator training. These two effects are typical of the transfer of training of complex tasks from a training device to the actual situation and are indicated by CTERs of less than 1.0. The CTER is .79 and is somewhat higher than Takeoff to a Hover and Landing from a Hover. The training effectiveness of the simulator for these three hovering maneuvers are similar and all indicate that the simulator is more difficult to hover than the aircraft. It is difficult to determine why this is the case, but it is believed to be due to the limited fi[illegible]d of view, the infinity focus presentation of the visual system, and the lack of other depth cues.

SHALLOW APPROACH

The learning curves for Shallow Approach (Figure 5) are similar to those for the hovering maneuvers. The Shallow Approach requires more training in the simulator and transfers to the aircraft with a decrement in performance. The trials to criterion CTER are .58. The difference in training transfer observed between the Shallow Approach and the Steep Approach (CTER = 1.0) is attributed to the longer time spent near the ground in the Shallow Approach. Near the ground the importance of the visual system field of view and focus is close to that required for the hovering maneuvers.

PINNACLE RECONNAISSANCE

Along with the Confined Area Reconnaissance, IPs believed that the limited visual field of the simulator eliminated any effective training of Pinnacle Reconnaissance. Therefore, four of the twenty-four students in the simulator group were not trained on

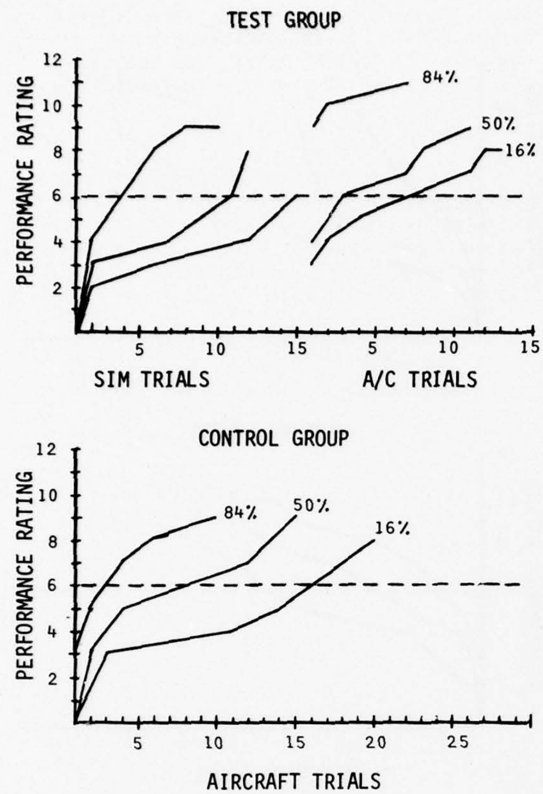

Figure 5. Shallow Approach

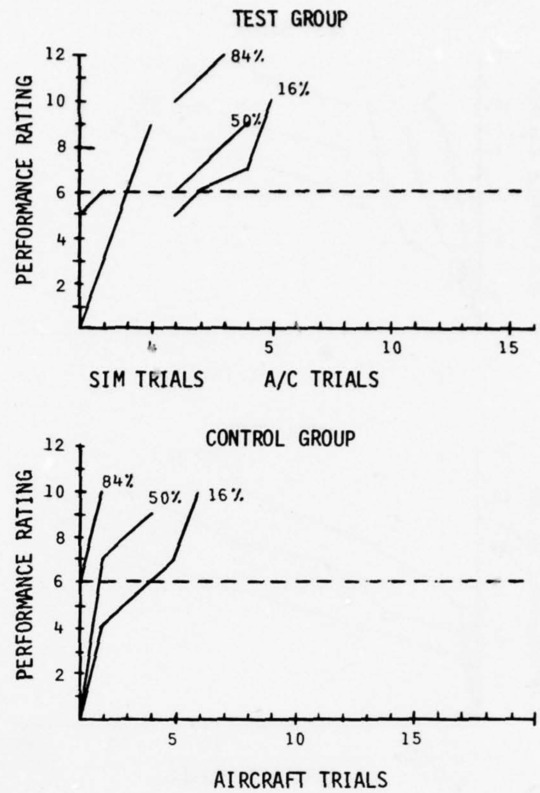

Figure 6. Pinnacle Reconnaissance

this maneuver in the simulator. However, the learning curves (Figure 6) do not support this conclusion but indicate that the maneuver is quickly learned in both the simulator and the aircraft. As was the case with some of the other maneuvers (Confined Area Approach and Landing) which were learned in a very small number of trials, it is difficult to determine the actual training effectiveness of the simulator. The CTER is .50 but is based on such a small number of trials that it is difficult to defend with confidence. The learning curves for Pinnacle Approach and Landing are similar to those for the Pinnacle Reconnaissance in that the maneuver is learned quickly in both simulator and aircraft and its CTER is zero.

STUDY II

COMBAT READINESS FLYING

METHOD

The objective of this study was to experimentally determine the extent that combat readiness flying skills trained in the CH47FS can be maintained and transfered to the aircraft. The determination was made on a maneuver by maneuver or task by task basis of maneuvers and tasks performed both in the CH47FS and the aircraft.

The method used followed a pretest-train-posttest paradigm. The subject aviators were given an extensive flight test at the beginning of the program, then trained in the CH-47 FS periodically for 6-months in addition to essential aircraft flying and then were given another flight test. A second similar group was given the two tests and flew the aircraft but did not receive CH47FS training.

SUBJECTS

The subjects for this study were 32 FORSCOM aviators qualified in and currently flying the CH-47. Sixteen of the aviators comprised the experimental group that received simulator training and the other 16 were the control group. These aviators were selected from two FORSCOM posts with equal numbers of experimental and control subjects coming from each post.

INDEPENDENT VARIABLE

The independent variable in this study was the use of the CH47FS in a combat readiness flying (CRF) training program. The 16 control aviators were requested to limit their flying during the 6-month test period to mission essential flying. Mission essential flying was defined as flight in a CH-47 essential to the support mission of the unit. They were specifically requested not to fly for training purposes nor to fly other aircraft or flight simulators. These aviators were exempted from meeting required flight hours and from taking required flight tests for the duration of the study.

The 16 experimental aviators were treated the same as the control aviators except for receiving training in the CH47FS. Each of these test aviators received 30 hours of training in the CH47FS during the 6-month test period. The training was given in 5-hour blocks once every 4 weeks over 6 of the 4-week cycles. The training program was designed to meet FORSCOM needs by the FORSCOM training representative, and included all of the maneuvers tested (see Table 2) plus others not tested.

PERFORMANCE MEASURES

The performance measures essential to this study were the ratings given each maneuver performed on the pre- and posttraining checkrides. These performance ratings were done on the same 12-point scale used in Study I. In addition to checkride ratings, the experimental group was rated on each maneuver practiced in the CH47FS as were the subjects of Study I.

OPERATIONAL PROCEDURES

The pretest inflight checkrides were administered to all subjects at the beginning of the 6-month study period by their unit standardization pilots under the supervision of the Test Directors. These data were collected at the field sites and brought to Fort Rucker for analysis. At this point, all subjects began flying mission essential flights only and recorded their flight experience.

Those aviators chosen to receive training in the simulator came to Fort Rucker at 4-week intervals. They trained in the CH47FS in pairs, two pairs per week, for approximately 6 months. The training was conducted by two FORSCOM instructor pilots trained to operate and teach in the simulator.

At the completion of training, all subjects, control and simulator trained, were given a second checkride identical to the first. Again, these checkrides were supervised by the Test Directors and the data returned to Fort Rucker for analysis.

RESULTS AND DISCUSSION

Data presented here are for an experimental group of 15 and a control group of 13 aviators rather than 16 each. Military and personal needs required four of the subjects to terminate their participation before taking the posttraining flight test.

During the 6-month test period, the simulator group trained in the CH47FS for a mean time of 29.7 hours and participated as copilots for a mean time of 26.4 hours. The mean CH-47 aircraft time for this group was 45.2 hours and for the control group 58.0 hours. This difference was not statistically significant ($\underline{t}$ (26) = 0.27, $\underline{p} > .5$).

The flight test scores were transformed by a procedure described by Hays (1967) to weight the score for each maneuver by an estimate of its difficulty. The difference between the control group's pre- and posttest score (52.5 and 53.7) is not significant ($\underline{t}$ (12) = .98, $\underline{p} > .5$). The difference between the simulator group's pre- and posttest scores (47.5 and 56.7) is significant ($\underline{t}$ (14) = 6.8, $\underline{p} < .002$).

Table 2 presents the mean ratings of each maneuver for the experimental group. The pre- and posttest means were tested for significant differences with the correlated $\underline{t}$-test and the $\underline{t}$ value and its significance level are tabled. The significance levels listed are for the two-tailed $\underline{t}$-test with alpha set at .05. All probabilities above .05 are considered nonsignificant. A similar table was constructed for the control group and only two of the 35 maneuvers had improved significantly (Straight & Level Flight and 2-Wheel Taxi).

OVERALL TEST SCORES

The significant difference between the pre- and posttests taken by the simulator group indicates that the simulator trained group improved its performance in flight in the CH-47 as a result of training in the CH47FS. The control group neither improved nor worsened over the 6-month test period. The CH-47 mission essential flying during the study period maintained this group's flying skill.

MANEUVER TEST SCORES

Table 2 compares the mean pre- and posttest performance by the experimental group on each maneuver. Seventy-four percent of the

TABLE 2

FLIGHT TEST SCORES BY MANEUVER FOR THE SIMULATOR GROUP

MANEUVER	MEAN TEST SCORES PRE	POST	t	p<
Cockpit Runup	6.6	7.8	3.1	.01
Taxi (4-Wheel)	6.6	7.2	2.6	.02
Takeoff to Hover	6.6	7.5	2.0	.05
Hovering Flight	6.3	7.3	3.1	.01
Normal Takeoff from Hover	6.3	7.7	4.2	.01
Traffic Pattern	5.7	7.0	3.2	.01
Normal Approach to Hover	5.5	6.7	4.6	.01
Landing from Hover	5.7	7.2	5.0	.01
Normal Takeoff from Ground	5.7	7.1	4.0	.01
Normal Approach to Ground	5.5	6.9	3.2	.01
Maximum Takeoff	5.4	6.9	3.7	.01
Steep Approach	5.5	6.6	2.1	.05
Standard Autorotation	5.1	6.3	1.6	---
Shallow Approach Single Engine	5.6	7.5	2.6	.02
Normal Takeoff w/NBC	5.5	6.3	2.2	.05
Traffic Pattern w/NBC	6.1	7.4	4.0	.01
Normal Approach w/NBC	5.1	6.3	4.9	.01
Maximum Takeoff w/NBC	5.5	6.8	3.3	.01
Standard Autorotation w/NBC	5.2	6.1	1.8	---
External Load Procedures				
Briefing & Hook Check w/NBC	5.7	6.4	1.4	---
Takeoff & Flight w/NBC	6.1	6.5	1.2	---
Approach & Landing w/NBC	5.5	6.2	2.0	---
Briefing & Hook Check	5.8	6.3	1.2	---
Takeoff & Flight	6.3	6.9	2.0	---
Approach & Landing	5.5	6.6	3.9	.01
Instrument Procedures				
Radio Check	7.7	7.4	0.6	---
Straight & Level Flight	6.5	7.3	2.17	.05
Level Turns	6.2	7.1	2.4	.05
Straight Climbs & Descents	6.1	7.3	3.5	.01
Approach, GCA	6.5	6.7	0.7	---
Taxi (2-Wheel)	5.4	7.2	4.7	.01
Cockpit Shutdown	7.0	8.3	4.4	.01
Emergency Procedures				
Engine Failure	4.9	7.3	3.0	.01
Low Side Governor Failure	4.9	7.1	3.2	.01
Transmission Oil Low	5.7	6.6	2.9	.01

tested maneuvers showed a significant improvement. The largest group of maneuvers that showed no improvement was external load operations. It is believed that this was due to limitations in the simulator's visual system. Autorotations also did not improve, probably for the same reason.

The results of Study II agree with those of Study I as to the maneuvers that are difficult to train in the CH47FS. Even though these maneuvers were difficult to train in the simulator, there is no evidence of negative training on any maneuver tested.

CONCLUSIONS

Study I on transition training and Study II on combat readiness flying both show that the CH47FS is an effective training device. For many maneuvers Study I indicates that it trains as well or better than the CH-47 aircraft (CTERs $\geq$ 1.0). Another group of maneuvers can be trained in the simulator with minor increases in the amount of practice required. These maneuvers had CTERs less than 1.0 but greater than 0.7. A third group of maneuvers had CTERs below 0.7. However, CTERs in the range of 0.5 to 0.7 do not indicate that a

training device is ineffective. Rather, they indicate that the training device is not as efficient in terms of the number of trials required to learn a particular maneuver as is the actual aircraft. In the case of a training device such as the CH47FS which has a large proportion of maneuvers with considerably larger CTERs, it also leads to speculation about the characteristics of the trainer that results in these lower figures.

The maneuvers that produced the lower CTERs were all maneuvers in which a substantial part of the maneuver was spent close to the ground. Examples of these maneuvers are: all hovering maneuvers, shallow approach, external load and pinnacle operations. In Study II the FORSCOM aviators did not increase in proficiency on autorotations and external load maneuvers. It is believed that these effects that occur close to the ground are due to limitations in the visual system.

The most obvious limitation in the visual system is the limited field of view (48^0 x 36^0). It seems that many of the visual cues normally used for hovering maneuvers are more than 24^0 from the centerline of the aircraft or 18^0 below the horizon. These cues may not be essential for hovering maneuvers, as is shown by the fact the aviators did learn to do them, but are available in the aircraft and do aid performance.

A more subtle limitation in the visual system is the infinity focus CRT display in the cockpit. Through the use of a beam-splitter and a curved mirror, the CRT display is made to cover 48^0 visual angle and is focused at infinity. A near object seen in this system does not have all the usual depth cues present to indicate how close the object is to the viewer. Since both eyes see the same scene delivered by the CRT, there is no stereoscopic disparity present. Since the scene is focused at infinity, there is not appropriate angle of eye convergence or lens accommodation. The result is that near objects appear to be farther away and larger than they should (Gregory, 1973). This discrepancy in depth perception may also be partially responsible for difficulties in hovering and in judging distances properly when close to the ground at the end of a landing approach.

The difficulties in judging depth in the visual display are especially critical in the chin window display. This display presents a checkerboard pattern through an infinity focus CRT display to represent the ground and to provide additional cues during an approach or while hovering. Drift cues are represented by movement of the pattern across the display as if each square of the display were a square on the ground 7- feet on a side. The only depth cue available in the display is the size of the squares. None of the expected monocular depth cues such as texture gradients, overlapping of objects, size of familiar objects or others are present. As in the main display, there are no stereoscopic disparity, eye convergency or lens accommodation cues. This results in difficulties in judging height, rate of closure, and rate of drift. These cues are essential to performing all maneuvers close to the ground such as the landing approaches and hovering maneuvers found to be difficult to perform in the CH47FS.

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ENABLING FEATURES VERSUS INSTRUCTIONAL FEATURES IN FLYING TRAINING SIMULATION

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In recent years, economic and resource constraints have forced members of the training community to actively seek more cost - effective approaches to routine training needs (Diehl and Ryan, 1977; Vandal, 1977; McEnery and Lloyd, 1977; Provenmire, Russel, and Schmidt, 1977). Within the Air Force, these constraints have resulted in efforts to reduce the overall number of flying hours (i.e., hours used for training in actual aircraft) by 25 percent by the early 1980's (Flight Simulators, 1976). In order to accomplish this goal, the Air Force is moving rapidly into the area of simulation in flying training (Dunlap and Worthey, 1975). While the use of simulation is not new to the Air Force (Valverde, 1968; Smode, 1974; Rivers and VanArsdall, 1977), use of simulation on such a broad scale as that directed by Congress is.

Within the area of flying training simulation, the concern has been expressed (Caro, 1977ab) over the extent to which instructional methods based upon traditional "in-flight" models provide the most effective set of techniques and procedures for conducting training in simulators. Such models, while obviously valid for teaching persons to fly, fail to capitalize upon the unique capabilities of simulators to free the instructional process of constraints imposed by the use of operational aircraft as training devices. Inasmuch as in-flight instructional models promote the continued use of simulators as surrogate aircraft, an upper limit on the effectiveness of simulators is set by the limitations of actual aircraft as training devices.

Bridging the gap between continuation of the traditional in-flight model of flying training instruction and a simulator-based model are those aspects of a simulator referred to as "advanced training features." It is not the primary purpose of this paper to review the present scope of advanced training features available for the conduct of flying training. Descriptions of training features believed to be representative of those likely to be found on early- to mid-1980 generation flight simulators have been described elsewhere (Faconti, Mortimer, and Simpson, 1970; Faconti, and Epps, 1975; Isley and Miller, 1976; Knoop, 1973, Smith and Simpson, 1972). Neither is it the intent to propose an instructional model for the most effective utilization of such features. The latter effort is currently being addressed by the Air Force Human Resources Laboratory under Project STRES (Simulator Training Requirements and Effectiveness Study).

Instead, the primary purpose is to present a conceptual framework for organizing and giving direction to research and development in the area of advanced training features. . . a framework that hopefully will not only bring structure to what is currently a poorly defined area, but that will also promote further instructional research into utilizing the "active" instructional capabilities of the modern day flight simulator.

Training Features: A Conceptual Framework

It is suggested that the unique training features of flight simulators might best be characterized as consisting of (1) enabling features, and (2) instructional features. One possible scheme for treating the differences between these two types of features is given below. It is hoped that the framework to be presented here will contribute to distinctions among training features in a manner that will also aid in clarifying those dimensions along which the effectiveness and suitability of such features can best be evaluated. While the chief concern here is with flight simulators, the distinctions to be made need not be restricted to this type of simulation device alone.

I. Enabling Features. Enabling features arrange for the occurrence of physical events and conditions that are necessary to support training but not for the manipulation of these events instructionally. Their training effectiveness lies in their ability to create the conditions under which training may occur, not in their direct effect upon pilot performance. Enabling features are typically the "given" part of the familiar three part behavioral objective. To the extent that enabling features can be separated from their particular application, the relevant dimensions along which their effectiveness should be evaluated are fidelity, ease of user operation, domain of task conditions simulated, etc.

Class 1: Environmental Conditions. Environmental conditions consist of simulated elements of the natural or man-made environment and/or their effects upon the aircraft being simulated. (e.g., maneuver and disturbance motion cues; visual sky/horizon/earth scene; sun image; G seat/G suit, grayout/blackout, target performance, size, and display, gaming area, electronic warfare and communications jamming, runway conditions, visibility/ceiling; day/night; other aircraft as in refueling, air-to-air combat maneuvers, or formation flight, tactical conditions and targets, cultural features, moving objects such as truck convoys, tanks, boats etc, and multiple objects such as offensive weapons, SAMs, antiaircraft artillery, or opposing aircraft launching a missile.

Class 2: Aircraft Conditions. Those features which relate directly to the physical operating status of the aircraft (e.g, fuel supply, center of gravity, engine status; malfunctions, etc.). Such features may also permit manipulation of the performance characteristics of opponent aircraft (e.g., varying the percentage of optimal performance of the opponent). In instances such as the latter, an enabling feature may be used instructionally for placing the student at a desired advantage or disadvantage.

II. Instructional Features. Instructional features consist of those provisions (available either through software manipulation or actual hardware component) by which the operator is able to manipulate enabling conditions in order to bring about desired changes in pilot performance. Evaluations of the effectiveness of instructional features are difficult, if not impossible, to make independently of the manner in which they are applied. Depending upon the intended function of the instructional feature, its effectiveness may be measured either in terms of instructor/operator performance or in terms of student performance directly. It is, however, the "effect" produced by use of an instructional feature that is of primary concern. Since instructional features do not represent "things" in any real sense, fidelity is not a relevant dimension for their evaluation.

Class 1: Passive Instructional Features. Those instructional features for which there is little or no direct contact with the student. Passive instructional features would include CRT and graphic displays used by the instructor, physical layout and actual utilization of console hardware, performance measurement in nonadaptive systems, procedural monitoring capabilities, etc. In general, the passive instructional features assist the instructor in performing monitoring and evaluation functions. To the extent that an instructor or operator must interact with information presented by such features, human factors criteria are appropriate both as a part of their design and their evaluation. To the extent that some designs may be more efficient than others, objective criteria based upon actual instructor performance in representative training settings are required. Evaluation methodologies such as those utilizing benchmark instructor/operator tasks for the evaluation of alternative display formats represent one alternative for further development as well as operational test and evaluation. The point to be made is that while such features are used instructionally, the primary effect is one measured in terms of instructor rather than student performance.

Class 2: Active Instructional Features. Those instructional features for which there is direct student contact with the feature. It is suggested that these features may be further subdivided into the following classes:

Subclass A: Those features which substitute for functions provided by the instructor in real-time and which may only

indirectly contribute to more efficient training (e.g., recorded preflight briefings and flight demonstrations).

Subclass B: Those features that contribute to more efficient training by eliminating or reducing "dead" time (e.g., use of freeze and preprogrammed initial condition sets).

Subclass C: Those features which allow the instructor to augment the physical cues available to the student (e.g., visual, auditory, and/or kinesthetic cues not normally present in the pilot's "natural environment," auditory/visual performance alerts, etc), or to use instructional methods not available in the aircraft (e.g., performance record and replay).

Subclass D: Those features that enable the instructor to "restructure" the basic characteristics of the task or the way in which the task is performed (e.g., control of task "tempo," ground position freeze, axis (parameter) lock, etc.).

The Application of Instructional Features

While elements of the first two classes of "active" instructional features contribute to more efficient flying training (principally through making available more practice time per session), neither represents a true departure from the basic elements of the traditional in-flight model of instruction. The demonstration, for example, is most often used only in its most rudimentary form, that is, as a canned, prerecorded version of an in-flight type demonstration. Rarely is the demonstration capability used jointly with other features to create an instructional capability beyond that which is possible under normal in-flight conditions. While significant research problems still remain in these areas (for example, determining the most effective manner in which to manipulate the content and placement of the recorded demonstration), innovative applications of simulation to flying training reside in manipulation of Class C and Class D type instructional features.

An Example:

Consider, for example, the following application of advanced training features to the training of an air-to-surface weapons delivery task. As in many complex psychomotor tasks, the ability to diagnose ones own errors represents one of the difficult aspects of the task. In the air-to-surface task, one of the most difficult aspects to convey to the naive student is the notion of "compensating errors." While the "school solution" involves the student's being able to configure the plane so that certain release parameters are met, more often times than not the student hits the target because deviations in one parameter are compensated for by deviations in a second and/or third parameter. Under present methods of instruction, the manner in which these errors compensate is learned only through repetition of the task either in the aircraft or in the simulator. The conceptual aspect of this complex psychomotor task might better be taught through the integrated use of a number of the advanced training features.

Consider first the use of a preprogrammed initial condition set that when executed places the student at the correct release altitude, dive angle, airspeed, etc. Consider now the additional use of a bomb impact predictor cue (Hughes, Paulsen, Brooks, and Jones, 1978; Cyrus, Templeton, and McHugh (in press) that provides a continous and immediate depiction on the ground of where the bomb will impact. Finally, consider the use of the parameter freeze or axis lock feature to hold constant the student's airspeed, heading, and altitude, leaving dive angle free to vary. By employing the simulator now in a ground position freeze mode and giving the student control over the stick and rudder, the student can experiment with the effects of dive angle, for example, independently of other parameters and, thorough use of the predictor, see the results of these manipulations immediately on the ground without the normal delay associated with the flight time of the bomb. By freezing other parameters in a similar manner, the student is able to see directly how corrections in one parameter are able to compensate for deviations from ideal in another parameter. One might consider using such an exercise as part of an initial demonstration in addition to the traditional demonstration where the student sits back and passively watches a "canned" performance of the task.

Once the student begins performing the task, the instructor might consider the use

of other features. For example, the feedback delay inherent in the bombing task imparts a significant delay between the actions of the pilot at the release point and the feedback for these actions obtained when he looks back to observe the point of impact of the bomb. Learning theory would suggest that such a delay degrades learning. The delay might be eliminated in one of two ways. In one way, the system might be frozen at the moment the pilot releases the bomb and the impact point immediately illuminated. While the freeze would give the pilot the opportunity to check his release parameters and out of cockpit visual references without having to attend to flying the plane, the continuity of the performance is disrupted. The effect of such a disruption on the acquisition on a motor task is not known. Another alternative would be not to employ the freeze, but to illuminate the target the moment the pilot presses the trigger. Continuity of the performance is thus not disrupted and the inherent feedback delay interval is eliminated. As with any intervention into the training setting that alters real world conditions for the sake of training, the instructor must also consider ways in which to systematically withdraw such cues.

While not an instructional "feature" per se, the principle of backward chaining might also be used effectively in performances involving the chaining together of subtasks. According to the principle of backward chaining, the terminal, as opposed to the initial, links of the chain are acquired first. On the bombing task, for example, the first link of the chain to be acquired would involve the pilot's release of the bomb at the correct pickle point. The system might be arranged so as to have the simulated aircraft fly this segment of the task under computer control requiring only that the student press the bomb release button at the proper time. As with the suggested applications described above, the freeze and replay capabilities might also be intergrated into this approach. Once the student is able to recognize the correct release point, that portion of the task between release and the time the pilot rolls out on final might be added to the chain. As performance on each portion of the chain reaches criterion, the system would arrange for the next portion of the chain to be trained. Similar application of such a backward chaining approach might also prove to be beneficial in tasks such as the overhead traffic pattern, straight-in approach and flair, as well as in such tasks as carrier landings and aerial refueling. In the latter task, training might begin with the student attempting to maintain contact with the tanker boom, proceed next with making contact from a short distance out, and only then proceed to making the initial approach to the tanker from a normal distance out.

A Further Example

Consider a second, perhaps less complicated, example than the first and the type of research design that might be appropriate for evaluating the effectiveness of alternative instructional feature applications. The particular example involves the use of the performance record/playback feature either in the recorded demonstration or replay modes and weighs the benefits of using the feature against those to be derived from allowing the student to continue to practice.

During the course of acquiring the skill associated with performing a particular maneuver, the student frequently watches the instructor perform a demonstration of the task. While automation of the initial demonstration is widely used in flying training simulation, an issue exists as to the relative merits associated with (1) repeating the original demonstration (either in part or in whole), (2) making available to the student or instructor alternative, prerecorded demonstrations of the maneuver for viewing on subsequent trials, or (3) forgoing any repetition of a demonstration, regardless of format, for the sake of allowing the student the opportunity for further practice.

Those who advocate not repeating the original demonstration might argue that the original demonstration serves to establish for the student a "standard" against which he or she uses to compare his or her own subsequent performance. To repeat the demonstration a second or third time would simply be a duplication of the function served by the first presentation. It might be arugued on the other hand that the naive student does not on the first viewing of the demonstration attend to all the proper elements of the demonstration, and only with repeated viewings grasps the full intent of the demonstration. A less obvious, but equally likely possibility, is that repeated demonstrations serve to break

up periods of massed practice, giving rise inadvertently to an intermittent practice effect.

There are those who argue for the effectiveness of repeated demonstrations, but who call attention to the need for adapting such demonstrations to the particular needs of that student at that particular moment. These persons further argue that no prerecorded set of demonstrations will be found to be ideally suited to such individualized use. For such persons, a practical alternative to the use of the recorded demonstration might be the playback feature. By recording the performance of the student on each trial for subsequent playback, the instructor has the option for having the student view a performance that presents the very errors the instructor wants to draw attention to (in fact, the student's very own errors), to overlay on this visual presentation a narration that is ideally suited to that particular student at that particular point in time, and to present whatever portion of that previous performance he desires.

The alternatives, all realistic and feasible, give rise to an experiment where the following experimental conditions are present.

Condition 1: Following an initial demonstration of a maneuver, the student practices for some x-number of trials, sees a second presentation of the original demonstration, practices x-trials, etc. until some predetermined number of trials have been completed.

Condition 2: Following an initial demonstration of a manevuer, the student practices for some x-number of trials, rests for a period of time equal to the duration of the demonstration viewed by subjects in Condition 1, practices for some x-trials, rests, practices, etc. until some predetermined number of trials have been completed.

Condition 3: Following an initial demonstration of a maneuver, the student practices for some x-number of trials, continues to practice during that period of time alloted to students in Condition 1 for subsequent viewings of the demonstration, pratices for x-trials, etc. until some predetermined number of trials have been completed.

Condition 4: Following an initial demonstration of a maneuver, the student practices for some x-number of trials, then views an instructor-narrated playback of performance on his last trial, continues to practice, views playback, etc, until some predetermined number of trials have been completed.

Condition 5: Following an initial demonstration of a maneuver, the student practices for some x-number of trials, views a live instructor demonstration, practices for x-trials, views live demonstration, practices etc. until some predetermined number of trials have been completed.

While the spacing of demonstrations, playbacks, or whatever is a potentially important variable, their placement in the suggested study is arbitrary. So too is the student's "need" for the instructional event at the time it is programmed to occur in the study. The study, nevertheless, would serve to evaluate alternative instructional uses of the advanced features in terms of conditions having pragmatic consequences. Furthermore, it addresses the potential situation where the time-consuming use of an instructional event such as a demonstration or playback may be less preferred than continued practice on the part of the student.

The Need for Continued Research

While technological advances are likely to lead to the more efficient design of instructor/operator consoles and to more efficient management of the simulator's training features, basic instructional research is needed to determine the most effective manner for utilizing these features in actual training settings. As the move toward more fully automated training continues, one may expect to observe more and more functions currently performed by the instructor to come under computer control and management. There exists a limit, however, as to what extent such an engineering oriented approach to automation will ever fully utilize the unique capabilities of the modern day flight simulator. It is anticipated that the eventual outcome of such an approach will simply be the automation of an instructional approach derived from an in-flight model of flying training instruction. The insufficiency of such an approach for simulation-based flying

training instruction has already been alluded to here and elsewhere.

In flying training simulation, as in any other area of training, engineering principles simply cannot be looked to as providing the basis for a technology of instruction. The application of engineering principles must be looked to as providing a means to an end. . . an end that is defined behaviorally. Such a behavioral definition of flying and the instructional process that supports flying training represents a key effort in current research of the Flying Training Division of the Air Force Human Resources Laboratory.

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TRAINING EFFECTIVENESS EVALUATION: PAST AND PRESENT

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ABSTRACT

Training effectiveness should be the driving force behind the procurement and use of training systems. However, there are major difficulties to overcome in the evaluation of aircraft training systems effectiveness. The main difficulty stems from the complexity of the issue, which results in a lack of clear operational definitions. The Naval Training Equipment Center has initiated a research program in Training Effectiveness Evaluation (TEE), an initial part of which is to develop a model of the TEE process. The main objective of the initial phase of the program is to define the elements needed in TEE and to specify the interrelationships among critical elements. Another objective is to foster better communications within the training and operational community.

INTRODUCTION

One early attempt at aircrew training was a device known as "pin ball." The objective of "pin ball" was to train "live fire" sortees against other aircraft (Air Force, 1945). This was accomplished by gunners firing special "frangible" bullets which would not damage the armored target aircraft. The target aircraft had 110 microphones mounted on the fuselage. Any "hit" was registered through a microphone connected to a counter located in the cockpit. A hit also activated a red light in the nose of the target aircraft which would blink on for a short time (Figure 1).

"Pin ball" contained many aspects which remain as issues in contemporary training. The fidelity and realism of the device were high; and complete visual, motion and aural cues were supplied to the gunner. The device also provided immediate feedback to the trainee as well as objective performance measurement.

Contemporary training issues revolve around the levels of fidelity required for simulation and the costs associated with such fidelity. In ground-based aircraft simulation, for example, the requirement for motion cues has not been addressed satisfactorily. This issue is of great economic interest since platform motion bases are expensive and have a great impact on engineering design and facility requirements. Other contemporary issues that require attention are illustrated in the technical development of a 360° visual display and/or advanced means to substitute color in a monochromatic presentation. A crucial consideration is the question of how much more effective a training system could be with the addition of such technical achievements.

The effectiveness of a training system directly affects the performance of the output (i.e., the graduates) in post-training environments. Thus, the evaluation of training effectiveness is a critical link in the design and

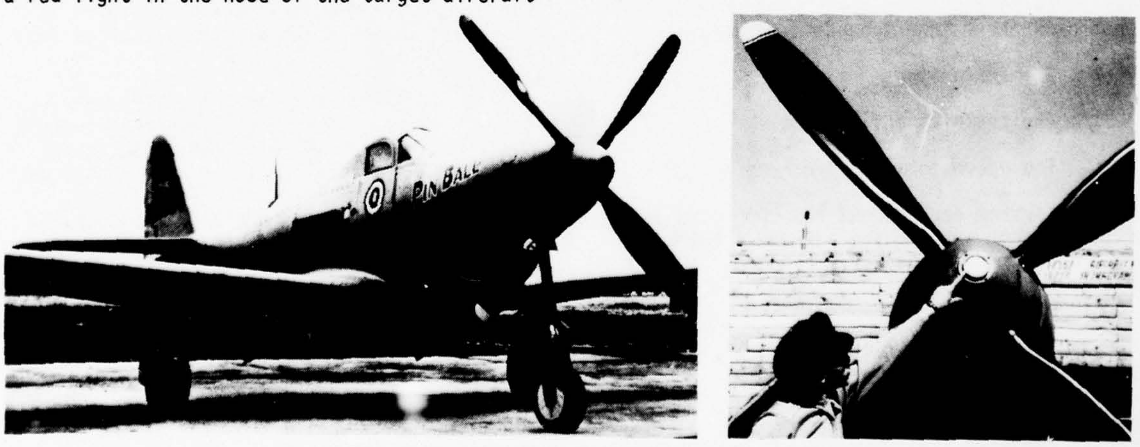

Figure 1. The "Pin Ball" Target Aircraft

use of simulators and training devices. It is clear that training effectiveness has a direct impact on combat readiness.

Contemporary TEE Difficulties

One of the major difficulties in the area of TEE is the lack of agreement on definitions for appropriate terms. For example, Johnson (1976) noted that no one can provide a precise definition of training effectiveness. Other investigators have questioned the basic validity of simulator training programs. "The effectiveness of almost all military simulator programs is being assumed, and, in many cases, these assumptions may be in error by significant amounts. There has been virtually a total absence of controlled tests designed to validate military simulator training programs" (Caro, 1977, p.11).

TEE at NAVTRAEQUIPCEN

The Naval Training Equipment Center (NAVTRAEQUIPCEN) is involved in research programs, as well as applied efforts to understand both the methodological and practical considerations underlying TEE. The program has taken on increased significance due to:

- Advances in the state of the art in simuation technology.
- Heavy emphasis on determining the costs related to simulation.
- Requirements to train personnel to perform increasingly complex aircrew tasks and tactics.

Elements of TEE

The objective of TEE in aircrew training is to assess how well a training system imparts skills and knowledge to a trainee, and how well the skills and knowledge are demonstrated in real world task performances. The process depends upon three interdependent elements:

- The trainee.
- The training environment.
- The operational environment.

Training system development has concentrated on the optimum interaction between the trainee and training environment; TEE concentrates on the interaction between the training and operational environments.

A vital requirement in training effectiveness evaluation is that there must be a match between what is required in the operational environment and what is trained. The match requires a clear specification of operational requirements, and the development of pertinent training criteria and related performance measures. The development of criteria must occur through a systematic process which examines longitudinal effects to ensure that all relevant operational factors are included in a TEE. Goldstein (1974) stated the issue succinctly. "Evaluation is only one part of a long-term systematic approach; therefore, it is necessary to pay particular attention to developing relevant criteria of learning and transfer performance" (Goldstein, 1974, p.213).

Another important requirement in TEE is the need for effective two-way communication and feedback between the operational and training communities. Unfortunately, such communication links appear to work ineffectively in many cases. Without such links, training will tend to be divorced from operational inputs. Further emphasis must be placed on developing more adequate communications.

An effective TEE requires that consideration must be given to the methods by which TEE's are conducted. TEE often has been conducted through the transfer of training (TOT) paradigm. TOT consists of comparing training performance to performance which can be observed and measured in an operational setting (Blaiwes, et. al., 1973). The comparison is difficult, as many divergent operational requirements must be integrated to develop criteria. Another specific method used to measure training effectiveness is the incremental transfer effectiveness function (ITEF) which deals with the time savings in a training situation based on the utilization of successive increments of training in another usually less costly, training situation (Povenmire and Roscoe, 1973). This is a useful measure to express time savings, but, it, like many other measures does not integrate training costs into its formulation. The usual assumption is that it is less costly to use a simulator for training. Yet Caro (1977) stated that no one knows which simulator programs are cost-effective since it is difficult to determine all the variables that affect costs.

Other considerations for a TEE include the attitudes of personnel (trainers, trainees, operational personnel) and the impact other variables in a total training system have on TEE. The variety of considerations make training effectiveness evaluation a complex effort. A useful way to view the many variables and their interactions is through the development of a multidimensional TEE model.

A Model of the TEE Process

A model of the TEE process is being developed to provide guidance for the determination of how well a training system meets operational requirements. The preliminary TEE Model (TEEM) is depicted in Figure 2.

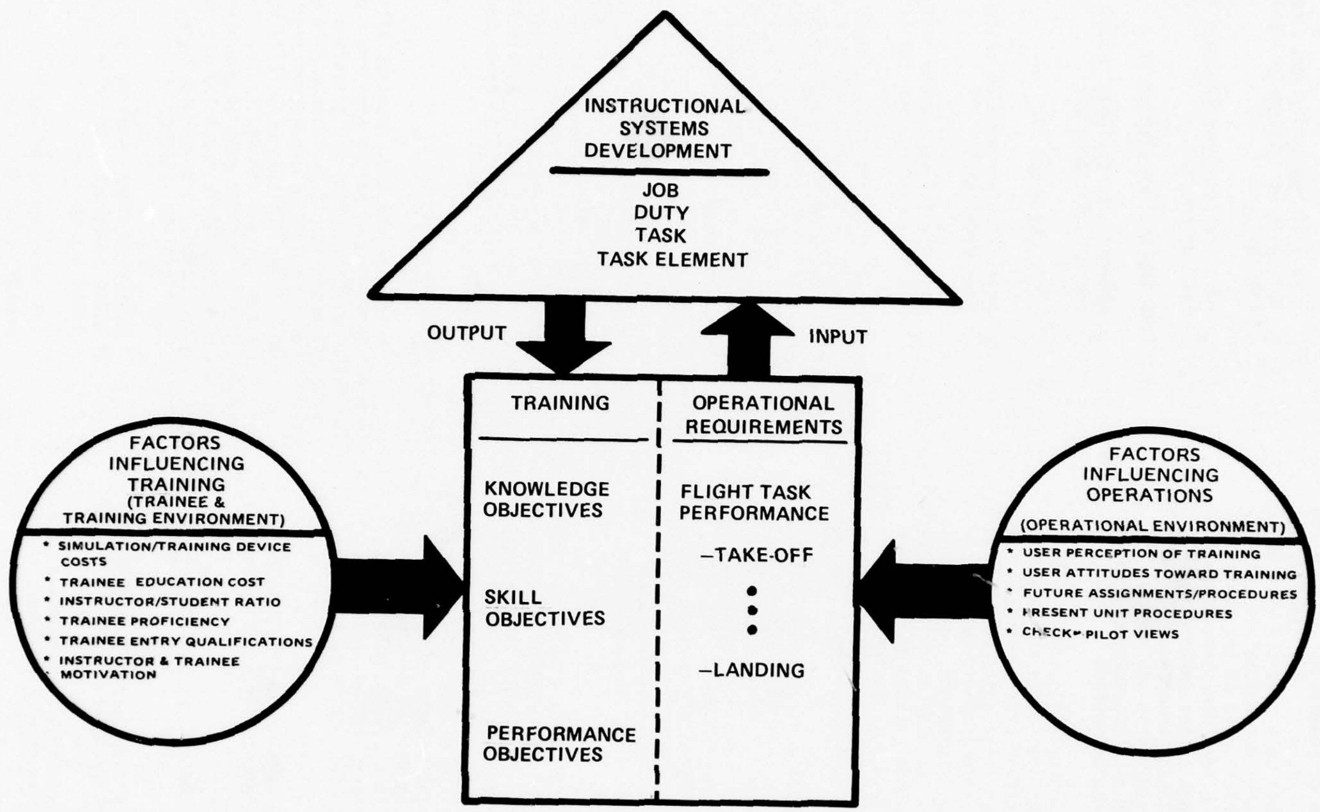

FIGURE 2 – TRAINING EFFECTIVENESS EVALUATION MODEL (TEEM)

The TEE Model was designed to examine the connection between operational requirements and training system components as shown in the central portion of Figure 2. For example, an operational task such as a take-off must be broken down into knowledge objectives and skill objectives which serve as the basis for the evaluation. The breakdown procedure is accomplished by means of the Instructional Systems Development (ISD) process. Through this process, necessary task analyses of job, duty, task and task elements are performed to specify training requirements.

The model also provides guidelines to develop factors that are not in the central portion, but are very important considerations in a TEE nonetheless. For instance, the model considers the influence from diverse subjective factors including personnel perceptions, attitudes and views; or objective factors such as influences from unit procedures. Factors such as future trainee duty assignments and experiences (longitudinal factors) must enter into the definition of operational influences.

Influences on the central portion of the model also occur from training factors (left hand area of the model). Resources, training personnel, facilities, devices and trainee ability all enter into training evaluation from the trainee and training environment. While most of the influences are objective, subjective attitudes of the trainee and training personnel must be factored into a TEE.

The major benefits of the model are that it can serve as a communication tool between operational and training groups, and that it provides an analytical tool for examining the TEE process in detail. Both of these aspects of the model are vital to the increased utilization of simulator outputs which include trained personnel as well as advances in simulation state of the art. The model is a necessary first step to define issues and problems related to TEE and to guide future research efforts.

The model may also be used to develop a checklist of the elements for a TEE including the following:

a. From the operational environment element --

- Have the operational requirements been fully identified?
- Have personnel perceptions of the requirements been analysed?
- Have actual and future squadron practices been considered?

b. From the training environment element --

- Have training device and simulator costs been properly identified?
- Have training personnel attitudes been determined.

c. From the trainee element --

- What are the trainees' views of the training program?

d. and from the model --

- Have valid performance criteria been developed?
- Have all relevant costs influencing the training been identified?

The model also can serve as a means of integrating on-going research results and attempts at developing performance measurements. One Air Force effort will attempt to apply automated performance measurement techniques within a C-5A aircraft. The objective of this effort will be to compile operational data which can be compared directly to a simulated system. Another effort, which is reminiscent (in objectives) of the "pin ball" system described earlier, is the Fairchild TOW Helicopter Installed Television Monitor and Recorder (HITMORE) developed for real-time monitoring and assessment of aerial gunnery performance. This system provides immediate post-mission playback and analysis of gunner aim-point during live or simulated firings of the AN-IS-TOW COBRA Weapon System (Ayral and Chandler, 1978).

Additional Research in TEE

The model as developed requires validation and improvement, but it can form a basis for defining TEE problems and solutions. In almost all endeavors it is important to define elements of a problem before attempting to specify solutions. This is especially true with TEE since it is a complex topic. The methodologies to address many of the elements have not been completely specified and need additional research. Some methodologies that might be beneficial to TEE are:

- Multidimensional scaling for performance measurement may offer a promising way to assess crew proficiency.
- The measurement of longitudinal variables such as retention must be addressed; transfer of training to the operational environment must show retention, otherwise the training program may not be worth the cost

- Cost-effectiveness analysis has not been successfully applied to TEE; relevant costs must be determined.

With the increasing role that TEE now plays and will play in the future of Naval aircrew training, a comprehensive research plan must be developed to address issues such as these. TEE must, therefore, be included as an integral part of all training systems.

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CONTRACTOR MAINTENANCE OF TRAINING DEVICES - ANSWER OR ALTERNATIVE

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INTRODUCTION

Training Devices, in one form or another, have been with us ever since man first discovered that by conveying his experienced skills to those who were inexperienced, he could more readily house, feed, and defend himself. The requirement to maintain training devices has also always been with us.

Training devices took a giant step forward with Ed Link's invention of the famous Link Trainer. Since that time, each step in the development of training devices has been tied to growth during periods of war or peacetime crises. With each step, however, the problems associated with training devices became more severe. The cost of software has more than doubled; the cost of hardware has grown greatly; and personnel related costs have steadily risen, from 46% of the Defense budget in 1968 to 61% in 1976.[1] Dramatic increases in the cost of training, logistic support, retirement benefits, and administration of the military and Civil Service work force have plagued the Department of Defense.

Contract maintenance has been viewed by many as the logical answer to the dilemma of doing more with less dollars. This paper will discuss many of the pros and cons of contract maintenance to support the contention that although it might not be THE ANSWER in each situation, contract maintenance is indeed a viable alternative that should be carefully considered when weighing all maintenance factors.

BACKGROUND

The advent of the Link Trainer was followed by World War II and the expanded use and application of training devices. Although the cost of trainers was relatively inexpensive when compared to the cost of aircraft, there were many new problems to overcome. The resolution of these problems led to new concepts in training evaluation and measurement, procurement, maintenance, and logistic support, and new assessments as to the qualifications and training of trainer maintenance personnel.

Due in part to the chill of the Cold War, the communist scare of the late 1940s and early 1950s, the growing military might of Communist China, and the lessons of the Korean War, the need for a highly trained fighting force did not diminish. In those days, as many of you may recall, a nation's military might was measured by the number and sophistication of its various weapon systems. Material needs took precedence over humanistic needs as "people" took a backseat to the steady procurement and development of new weaponry.

As our weaponry became more complex, so did the skills necessary to maintain it. The military countered with a broad system of personnel screening and classification, technical training, on-the-job training, and improved management, control, reporting, procurement, maintenance, and logistic support. The name "synthetic trainers" was applied to virtually all training devices.

Synthetic trainers were basically simple electromechanical devices that tried to duplicate certain aircraft functions. Our flight crews were well into the Jet Age while synthetic trainers were still trying to improve the performance and capability of long outdated systems. Many decision makers, both in Congress and the military, questioned the validity of trainers as an effective aircrew training aid. In addition, large numbers of aircrews resented the mechanical monsters and saw them as a threat to actual flying.

Between 1950 and the early 1970s, there were budget, personnel, and program cuts. These cuts were influenced by the race for space and a shift of priorities, the Cuban and Lebanon Crises, the Arab-Israeli Wars, major changes in our defense posture, new concepts and philosophy, Vietnam, a wholesale shift in the world economy, and the rebirth and rise of the Arab States.

On the sidelines and virtually unnoticed, the synthetic trainers slowly matured and were replaced by the far more complex simulator, but the entire training devices field remained hidden in shadow. While the sophistication of aircraft systems and other weaponry created a high degree of specialilzation and a vast new array of military job skills, the training devices field remained relatively small and the technician was then, as now, a jack-of-all-trades. Personnel assignment and classification policies, technical training, and maintenance were basically the same in 1972 as they were in 1952. With the development of the versatile computer, a whole new technology was being applied to simulators.

Despite early warning signs, the Energy Crisis of 1973/74 caught the entire nation unprepared. Almost immediately there were new

national problems and a new set of values — and the dramatic theme was energy conservation.

The Federal Government swung into action. The GAO, OMB, the President's Scientific Advisory Board, as well as earlier McNeff Report keyed on the increased use of training devices to reduce flying training costs and to conserve energy. The military services were directed to institute a comprehensive analysis of their present and future simulator requirements. The Air Force alone requested more than 150 new simulators and major modifications to existing devices. The cost of this simulator modernization and research was tagged at three billion dollars.[2]

The use and technology of simulators advanced at an unprecedented pace — and simulators moved from the shadows into the stark reality of the Computer Age. Thus, in 1974, time and progress finally caught up with training devices and, within the military, the small, well hidden training devices field was totally unprepared for the technological invasion.

This invasion has resulted in rising costs in all areas, major problems in simulator maintenance, and problems in logistic support. Most of the major problems, however, have been personnel related.

Despite the extraordinary efforts since the inauguration of the *all-volunteer* armed forces, recruiting has barely achieved its objectives. In addition, the number of noncombatant support personnel has grown at an alarming rate and many personnel with high school diplomas simply lack the basic skills to master today's technological demands. These demands are also compounded by the exodus of experienced enlisted personnel who are highly trained in the skills that are most salable to industry. The long lead times, the lengthy and expensive training, the technological explosion, and the shrinking defense dollar have mandated that DOD examine alternatives for system support. These alternatives have included the increased use of Civil Service and contract maintenance for the traditional enlisted manpower, or a combination of these alternatives. Since they do not "go to war," simulators are particularly viable candidates for contract maintenance.

The simulator industry has numerous examples of ongoing contractor maintenance programs: Singer and American Airlines are supporting the Undergraduate Pilot Trainers (UPT); AAI maintains both the Undergraduate Navigator Trainer (T45 UNT) and the Simulator (for) Electronic Warfare Training (T5 SEWT); Singer supports advanced simulators at both Williams AFB and Luke AFB; and Northrup has the entire base support function at Vance.

While there are more and more considerations for contract maintenance by various DOD entities, the "bottom line" is the cost comparison between organic, or in-house, and contract maintenance. There are, however, pros and cons to contract maintenance.

PROS AND CONS

What are the advantages of contract maintenance and why?

First and foremost, personnel costs are lower for contract maintenance than organic and/or Civil Service support. This is a definite concern since personnel costs now account for approximately 65% of the DOD budget and the emphasis is on reduced manning of noncombatants (or, if you will, increasing the "teeth-to-tail" ratio).

One major cost of personnel is that of training. The cost of a 24- to 36-week technical school course ranges from $20,000 to $25,000.[3] This does not include advanced skill level training, Type I training, special training, and various OJT, management, social actions, NCO leadership, and advanced leadership courses. The cost of training Civil Service personnel is somewhat higher due to the higher rates in pay and per diem.

While in training, the individual is essentially nonproductive. Because of production delays or other unforeseen circumstances, the military technician or Civil Service employee could find himself trained and ready -- but with no equipment to work on. Although the individual may be employed elsewhere, a loss of technical proficiency on the device for which the individual was initially trained will probably occur.

Inherent in many training devices is the requirement for an operator and, in some cases, an operator/instructor. With most training devices, an operator can be easily trained within a month. The instructor usually requires two to three months to reach the desired proficiency. Because of the classification system, ALL training devices personnel must attend the technical school. Of the 24- to 36-week school, only 2 weeks are directed toward operator duties and skills while the remaining 22 to 34 weeks are geared toward maintenance knowledge and skills. Despite the $20,000 to $25,000 technical school investment, many school graduates remain operators throughout their initial enlistment. Additionally, personnel find that they must prove themselves as operators before undergoing OJT to make them knowledgeable and productive maintenance personnel. In many cases, fully three years (of a four-year enlistment) have passed before the first term enlisted technician becomes an integral part of the on-equipment maintenance team. In effect, a near-$25,000 training investment is not commensurate with the maintenance output of one productive year!

Under contract maintenance programs, the contractor is responsible for and, more importantly, liable for providing fully trained, capable maintenance personnel at the point he accepts responsibility and for the life of his contract.

The contractor normally achieves lower costs by providing fewer people to perform equivalent jobs. Unimpeded by supervisory classifications, nonjob related training, meetings/briefings, manning, and other requirements, the wise contractor seeks to maximize personnel efficiency. With personnel that are normally more experienced and of higher skill levels than military personnel, the contractor has no manning constraints and can usually keep his supervisory staff at a minimum.

In most cases, the contractor can supply an experienced, stable work force. If training is required, the contractor sends fewer personnel and the training is tailored to exact needs. The contractor can also achieve economy by having his training school graduates train the remaining work force. Due to the experience levels of his people, contractor training can usually be compressed into much less time. Finally, because of his flexibility, the contractor does not require a long lead time for training. His training program can be readily geared to the production or modifications schedule of the device in question. As a result, the loss of technical proficiency is unlikely.

A significant advantage of contractor maintenance is assignment stability. The axiom that "maintenance is maintenance" is akin to exclaiming that if one can fly a Piper Cub, one should be equally proficient at flying a Boeing 747. Each simulator and each simulator system has its own peculiarities. The theory that separates pilot from navigator, ECM from gunnery, model board from dome visual, and a six-degree from a four-degree motion base plays a primary role in the maintenance of that equipment. There is no known substitute for experience. In many cases, about the time the enlisted technician feels at home on the device, he is reassigned. Although the personnel assignment system can withhold assignment under certain conditions, it rarely happens. The contractor does not have this problem.

An item of cost in personnel-related issues is that of administration. The administrative time and costs associated with the military are significant. The contractor is bound by contract to manage and control his employees; thus he essentially performs all the functions formerly accomplished by the various military supervisory and command levels. In some cases, contractor maintenance provides an appreciable reduction in the personnel administration areas.

Another major consideration is risk. We know of no system or procedure whereby the Government is relieved of all risk. Even if a contractor fails to perform and incurs a monetary liability for his failure, the Government is still left with an unfilled program or training requirement. We must also recognize that the contractor is in the business to show profit. He lays his reputation on the line with each contract and most contractors would rather pump in whatever is required than to admit failure. If good news travels fast, bad news travels even faster. Thus, we believe there is a degree of shared risk by both the contractor and the Government.

As the buyer, the Government sets conditions and establishes performance criteria for contractor maintenance. In essence, the contractor who bids on the proposal is stating that he can meet the requirements, is willing to assume the monetary risks, and can do the job at less cost than a Government work force. In a training device utilization program that is highly structured and tied to a rigid incoming and outgoing student pipeline, an efficient contractor can greatly reduce the risk and possible damage to the course and student pipeline.

A final factor for contract maintenance is a potentially lower development cost. This can occur when the contractor is permitted to develop only that data which he himself deems necessary. For example, a contractor could feasibly maintain a complex system using only schematics, wire lists, interconnecting diagrams, and engineering sketches. Obviously, this major cost reduction in development denies the Government the capability to solicit future competitive bids and/or assume the organic maintenance responsibility without incurring considerable cost.

While on the subject of simulator development, one cannot escape the enormous cost of a modern simulator system. Major modifications have also compounded simulator costs. This cost represents a "sunk" cost and the only sure method to recoup the investment is to maximize the use and capability of the simulator system throughout its life expectancy. This equates to optimum maintenance efficiency. Moreover, the new breed of state-of-the-art devices has taxed the military's ability to keep pace. Technical innovation not only affects personnel but logistics support as well. Here, too, contract maintenance can fill in the gap. Many of the factors cited above are not new. Military decision makers have been, and are, dealing with the perplexing problems associated with simulator maintenance. The natural alternative to a military work force is Civil Service; however, with even higher pay rates and administrative costs, Civil Service has many of the same constraints as the military.

The industry has cited numerous cost effective contract maintenance operations.[4] In one instance, nearly 75 military and Civil Service employees were replaced by 26 contractor personnel.

The prime disadvantage of contract maintenance is the untenable position of the Government if, for any reason, the contractor fails to perform. This situation can be especially acute if the Government, as mentioned earlier, has not procured the necessary engineering and technical data. It would be difficult, if not impossible, for another contractor to assume the risk. Should the Government elect to take over the maintenance responsibility, personnel would have to be located and trained and, in the interim, there would be limited productivity of the device and the people associated with it. In any case, the cost to the Government, in time, performance, and dollars, would be significant.

Another argument against contract maintenance deals with the sole source contractor. The contractor may have developed the technical data or be highly specialized to the point where there is no competition or he may have simply maintained the device for so long that no one else is interested in competing for the contract. In short, the contractor becomes the recognized expert and, as such, what is to prevent him from escalating the cost beyond reason? Along this same line, there is yet another argument against contract maintenance. Stated simply, the contractor is in business to make a buck; thus, he may take shortcuts, run a "body shop," and only perform just to get by.

These are certainly strong arguments; however, they are not absolute. Our industry is built on free enterprise and free competition. Just as the Government watches industry, we watch each other. We are indeed in business to make a profit and we can obtain that profit and continued profit, only by satisfying the customer or buyer. If we fail, we have not only tarnished our reputation throughout the industry, but have negated our chances for other Government contracts as well. Moreover, the Government is the buyer and it is the Government, not the contractor, who establishes the conditions and performance levels of the contract. The Government can and should minimize its risk by making the training of a replacement a provision of the contract. This would serve to protect both the Government and program continuity.

Some of the major pitfalls of contract maintenance were also discussed in an Air Force Air Command and Staff College research paper.[5] The author skillfully debated the issues, negative aspects, and remedies for the Government to avoid many of the problems related above.

Also considered disadvantages of contract maintenance are the real and perceived problems of contractor/Government interface and the attendant turmoil inherent in this situation. Frankly, there is usually some difficulty in integrating the contractor into a military environment. Despite a growing number of contract operations, there are a vast number of military personnel who neither know nor understand the meaning of a non-personal services contract. Conversely, many contractor personnel do not know military practices and procedures. The tendency of the military is to place <u>everyone</u> in the organizational chain and to exercise some degree of control. The tendency of the contractor is to resist this. The resultant situation strains relationships, affects morale, and hinders operations. The contractor "works for" and is responsible to his contracting officer. Legally, in most cases, all Government communications pass through the contracting officer to the contractor and vise versa. This procedure is sometimes misunderstood and often disagreed with by the military operations and maintenance hierarchies. In practice, however, both parties must recognize that rapid and direct communications are advantageous to both. The importance of amiable relationships and rapport cannot be overemphasized for mutual understanding is <u>the</u> primary basis for good contractor relations.

To minimize the dangers of strained relationships and misunderstandings, all parties should be made aware of the organizational structure, performance specifications, and the responsibilities - and nonresponsibilities - of the contract maintenance team. Where minor out of scope requirements are required and have a minor impact on the contractor, we're quite confident the customer would receive the requested service without added cost. In our business, too, the name of the game is to keep the customer satisfied.

Large out of scope requests that require a major expenditure in time or manhours will certainly result in contractor payment requests. Normally, the contractor does not expect remuneration for added effort of his own making; however, he will usually seek payment when the effort is not his fault. This brings up another aspect of contractor maintenance: weekend, holiday, special, or unforeseen training or work and the threat of contractor strikes or work slowdowns/stoppages. The most obvious solution is to build contingencies for these situations into the contract. As for the threat of union squabbles and contractor strikes, cursory investigation indicates that the Government has experienced far more difficulties with its own Government employees' unions than with simulator industry contract maintenance operations. (This, however, is not necessarily true with reference to simulator contractor production facilities.) In

addition, Government union agreements and regulations also restrict the flexibility of Civil Service employees to respond to shift changes, weekend/holiday work, and training schedule changes. It should be noted that all Civil Service overtime must be approved before it can be authorized. Most contractors do not have this constraint on their work force. By building performance measures (as opposed to time and material requirements) into the contract, the contractor must respond and the Government could care less how he schedules his employees to meet the requirement.

Another complaint regarding contractor maintenance is the question of manning in a national emergency, the manning of overseas sites or operations in combat zones. Various contractors have maintained successful overseas operations for years - and that also includes Korea and Vietnam during wartime. Of course, simulators do not go to war and for the most part, their high cost, fragile equipment, and need for air conditioning do not lend themselves to combat operations. As for the high cost associated with overseas contract operations, we know of no existing low-cost operation overseas or in a combat area. Where operating costs are high and the risk is great, the contract costs will be commensurate - and that's the way it is.

A final argument against contract maintenance is the determination of performance standards or measurements. As stated earlier, all participating parties should be aware of and fully understand the contract maintenance measures of acceptable performance. The question is "what should that performance be?" or "how do you evaluate the performance of a contractor?" The same rules that apply to the military or Civil Service do not necessarily apply to the contractor. As an example, most Government and military regulations and manuals are designed to control the output through a high degree of supervision and control over the work force. The legal ramifications of a nonpersonal services contract are such that the Government is expressly forbidden to supervise or control contractor employees. This does not mean the Government relinquishes total control over the output; it merely means the output should be contractually defined.

The usual performance criterion has been students in, or scheduled, versus students out, or completed. While this is one valid measure, it is by no means the only measure. Other tangibles such as logistic support cost, the extent of local repairs - or the lack thereof, top priority requisitions, and user comments can be effectively utilized to measure contractor performance more accurately.

There may not be an answer to the question of what contractor maintenance performance measures should be used, but this is an area for further investigation by both Government and industry.

CONCLUSIONS

We have discussed the history, the pros, and the cons of contractor maintenance. But what does it all mean? Is contractor maintenance the answer — or alternative?

We believe that the pros of contractor maintenance far outweigh the cons and while contractor maintenance may not be the answer for all simulators, it definitely should be considered as a viable support alternative.

To be objective, it is extremely difficult to avoid bias on any subject wherein one has a vested interest. To be sure, the major considerations for simulator contractor maintenance are less cost and a high-degree of flexibility. The arguments against were quickly dispatched, at least on paper. In practice, however, disagreements are not always easily resolved. In our business, it is virtually impossible to hide failure, incompetence, or unsound practices. The Government obtains some degree of protection by contracting with reputable, proven, and reliable firms, for they have the most to lose should something go awry. This success or failure of any contract is not dependent upon the actions of the home office but upon the individuals or teams in the field. With this in mind, a close rapport and a mutual understanding are two of the primary keys to successful contractor maintenance.

We believe all would agree that contractor versus organic support merits further investigation. Cost avoidance can be realized from the standpoints of labor savings and, if the Government desires, Engineering and Technical Data costs. The Government does run the risk of being in a sole source situation with a contractor, particularly if engineering technical data is not procured, and it is true that in the past, some major contractors have gone out of the training device business which could leave the Government in an untenable position.

Again, we believe the pros far outweigh the cons and recommend that the Government expand its consideration of candidates for contractor maintenance as well as investigate areas impacting contractor maintenance activities, such as contractual vehicles and methodologies for measurement of performance.

Why contractor maintenance? To sum up all the rhetoric in two words: less cost. President Carter summed it up neatly when he stated: "When the Government must perform a function, it should do it efficiently. Whenever free competition would do a better job of serving the public, the Government should stay out."[6]

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SIMULATION OF THUNDERSTORMS

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INTRODUCTION

Thunderstorm presence is required to fully complement a weather environment simulation. An in-flight aircraft will be subjected to forces in part created by moving air in this environment which can be described by clear air turbulence characteristics.

When the aircraft enters a thunderstorm area, the forces acting on the aircraft due to moving air can undergo a large change.

There are other phenomena related to thunderstorms that also have to be considered:

- o Lightning
- o Thunder
- o Icing
- o Radio Noise
- o Intensity Level Reflectivity

TYPICAL STORM CELL DEFINITION

Reference is made to Figure 1 that illustrates an isometric view of a typical simulated storm cell. The cell is defined as a parallelepiped that encompasses an inner volume containing the simulated storm. The vertical distance, h_s, defines the altitude of the lowest face of the cell. The vertical length of the cell is defined by h_c. Cell coordinates (X_N, Y_N, h_N) define the location of any point internal to the cell. The corner boundaries of the cell are referenced to a prescribed Gaming Area in terms of earth coordinates and altitude (λ, σ, h_s). The volume below the storm plane contains winds consisting of either rising, falling or horizontal drafts. A library of storms can thus be made available described by intensity α_F, or α_R, and an associated height, h_c.

Reference is made to Figure 2 that illustrates a planar view of a typical storm cell model. The storm is contained within a predetermined area bounded by a ½ mile square (by definition). The shaded area represents the storm environment and the remaining area within the square depicts clear air turbulence.

CHARACTERISTICS

Thunderstorms in general can occur individually over relatively small areas or they may exist along a wide front. The individual storms can be described as a "cell" and the frontal area storms can be described as a "storm line."

Throughout most geographic areas, thunderstorms are continuously forming into violent turbulent wind states and decomposing with dissipating winds accompanied by intense rainfall.

During the initial, or cumulous, phase of a thunderstorm, storm intensity increases due to the presence of an unstable, moist air mass that is carried upward by strong drafts. This moist air takes on the form of globules of water which in turn forms into snow and ice pellets as the air stream works further upward.

The initial storm phase is identified by random updrafts whose velocity can vary between 10 and 50 miles per hour at the storm base during periods between two and six seconds. These intensities increase as the updrafts rise in altitude within the thundercloud, or storm cell. During this phase, air is continuously being drawn inward and upward from below the storm base.

As the storm increases in size, the characteristics of the wind currents change. This second, or mature, phase is described as follows:

At some point, the density of water globules and ice pellets cannot be sustained by the upward air thrust and downward wind currents start to form. The proportion of downward air currents continues to increase accompanied by rainfall and possible hail or ice particles. The storm clouds continue to

grow and tend to scatter out at the top. In this case, the downward winds increase in intensity as they descend. During this phase, the winds below the cloud base are both flowing outward and inward from the storm cell.

The final, or dissipating phase of the storm consists of intense rainfall with downward winds. The rainfall and winds gradually slacken and the storm is dissipated.

STORM DYNAMICS

The cumulous storm phase consists of wind intensities $\alpha_R = N_1 K_1 N_2\ (h_s - h_N) + K_2)$ where:

N_1 is a Gaussian random positive amplitude

N_2 is a Gaussian random time period

K_1 is a proportionality constant

h_s is the storm base altitude

h_N is an altitude within the storm limits

K_2 is the storm constant intensity at h_s

The wind intensity below the storm is described as:

$$\alpha_{RB} = N_1 N_2 (K_3 \bar{u} + K\ \bar{z})$$

where:

K_3, K_4 are constants

$\bar{u}$ is the unit vector in the storm base plane

$\bar{z}$ is the unit vertical vector

Falling vertical winds are represented by intensities given by:

$$\alpha_F = -N_1 N_2 K_1 (h_c + h_s - h_N) + K_2)\ \bar{z}$$

where:

h_c is the storm altitude limit above h_s

STORM LINES

Thunderstorms can occur over a broad front. As a consequence, a storm front can be represented by groups of cells described above within realistic presentation areas of between 10 and 200 square miles. A catalogue of typical storm cells $S_1, S_2, S_3, \ldots S_n$ is to be provided for insertion in the Gaming Area. The location is to be preselected. Reference is made to Figure 3 which illustrates a representative multiple intensity storm front.

A thunderstorm area may also consist of a combination of multiple storm lines and individual cells. Reference is made to Figure 4 that illustrates a typical thunderstorm Gaming Area. Storm lines are precatalogued and located as shown by S_{L1}, S_{L2}, S_{L3} etc. Storm front S_{L3} is shown located at Gaming Area coordinates $(\alpha_{L3}, \delta_{L3}, h_{L3})$. Individual storms S_1, S_2, S_3, etc. are likewise located by Gaming Area coordinates.

An aircraft flight path as shown in Figure 4 may experience a wind intensity profile that is upward, downward, or bi-directional. Figure 5 illustrates three phases of storm dynamics contained in cells S_3, S_4, S_5. A moving aircraft can experience any of these profiles while in the storm area. As the aircraft enters another cell, a typical profile change is illustrated.

LIGHTNING

Thunderclouds contain a heterogenous array of charge formations. Many theories suggest that charge buildup is due to the driving energy, or a wind intensity within the thundercloud. The net effect is that a charge differential builds up both within the storm cell and also between the cell and earth's surface. Our interpretation of this phenomena is that lightning occurs when wind intensity levels or successive intensity level changes exceed a predetermined level.

Reference is made to Figure 6 illustrating the logic that provides a visual lightning cue as well as a radio aural cue. The present wind intensity (α_{ti}) is compared to the previous intensity (α_{ti-1}). If the intensity level difference exceeds a predetermined level reference, then lightning, thunder, and radio noise cues are provided.

ICING

In areas where individual thunderstorms are isolated, or scattered, icing is not considered to be a serious problem. However in areas of numerous thunderstorms, the icing problem can be significant. Therefore, thunderstorm icing discretes for icing simulation should be provided within severe storm line modules for altitudes above the order of 20,000 feet.

CLOUD SIMULATION

When the trainer aircraft enters a storm cell, or storm line, a cloud cover cue is sent

to the Visual System. Conversely, when the trainer aircraft leaves the storm cell, or storm line, a clear view cue is sent to the Visual System. The cloud cover cue is associated with the storm intensity.

SIMULATION BLOCK DIAGRAM

Reference is made to Figure 7 which shows a typical Thunderstorm Simulation Block Diagram.

Storm cell and storm line data are instructor furnished. These are generally selected apriori.

Aircraft equations of motion are supplied from another source. The items of interest involve own ship location and altitude. The location defines whether the storm volume has been intercepted. The ship's altitude is required to define wind components.

Two random noise generators are required to provide the storm amplitude and time periods. All cells within the storm front can be activated by the same two random generators. The individual cell characteristics will differ, however, in intensity and polarity.

Data base provides the time references needed for various phases of the program.

The computed functions of the program interface with own ships equations of motion in the case of wind intensity or icing. Visual cues are provided by lightning discretes. Scatter and storm distance information is also provided. Aural cues are provided by thunder and radio noise discretes.

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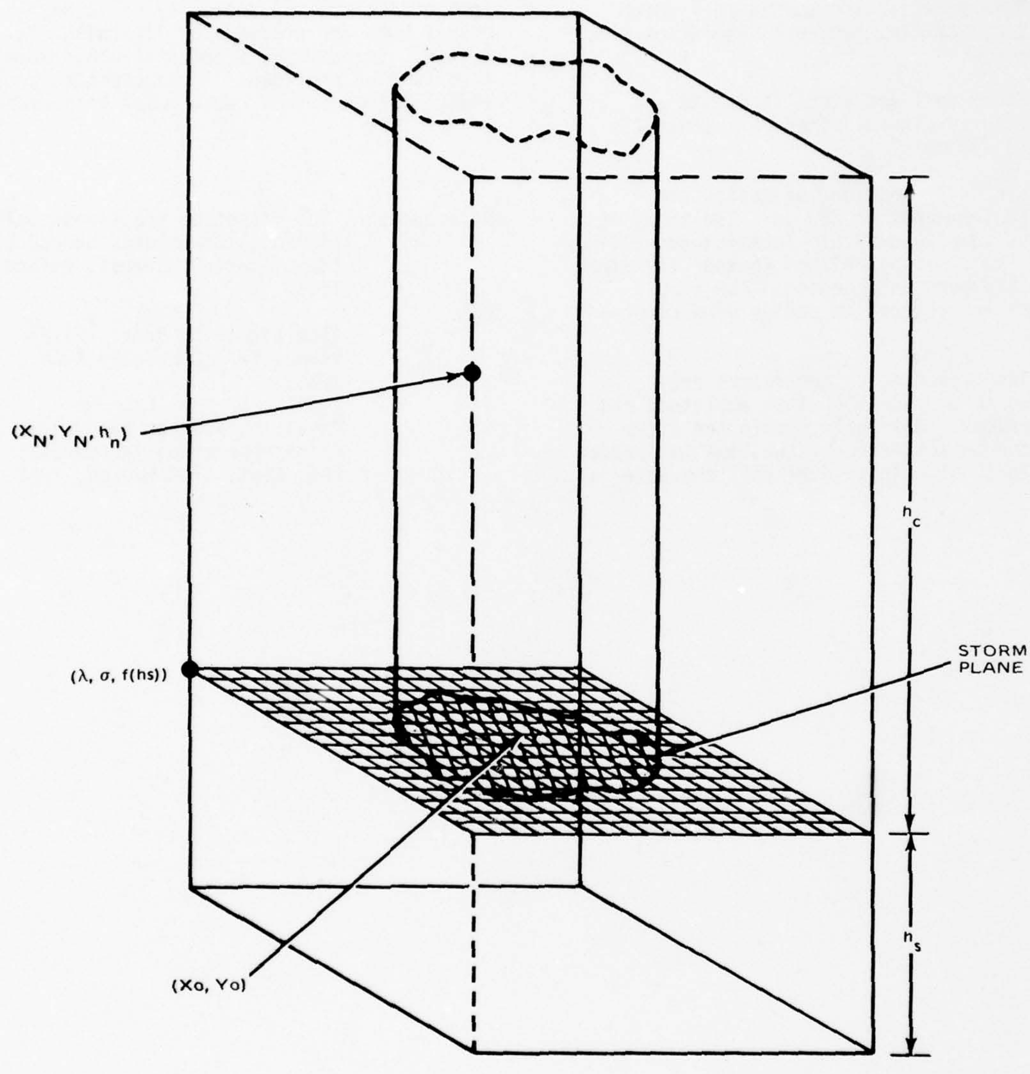

Figure 1 Geometric Presentation of a Storm Cell

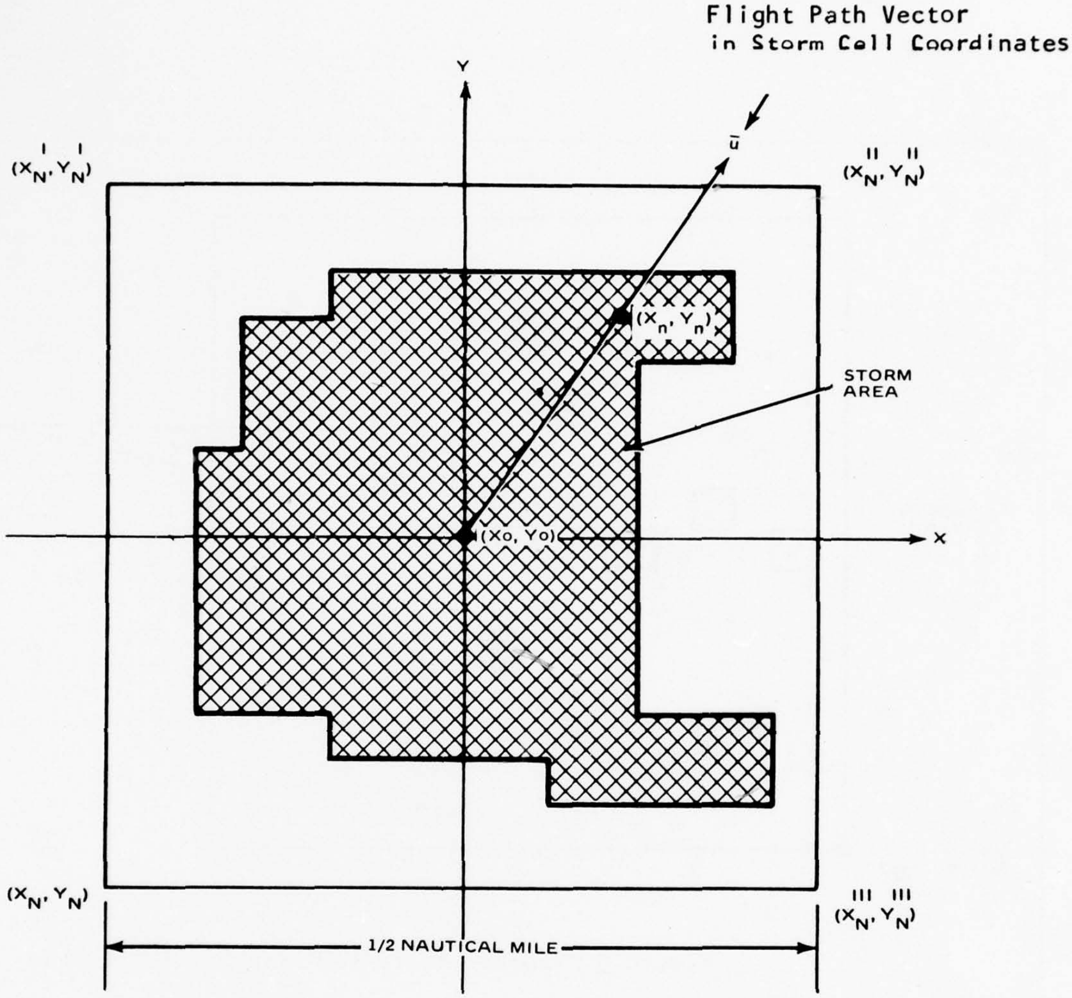

Figure 2 Planar View of Typical Storm Cell

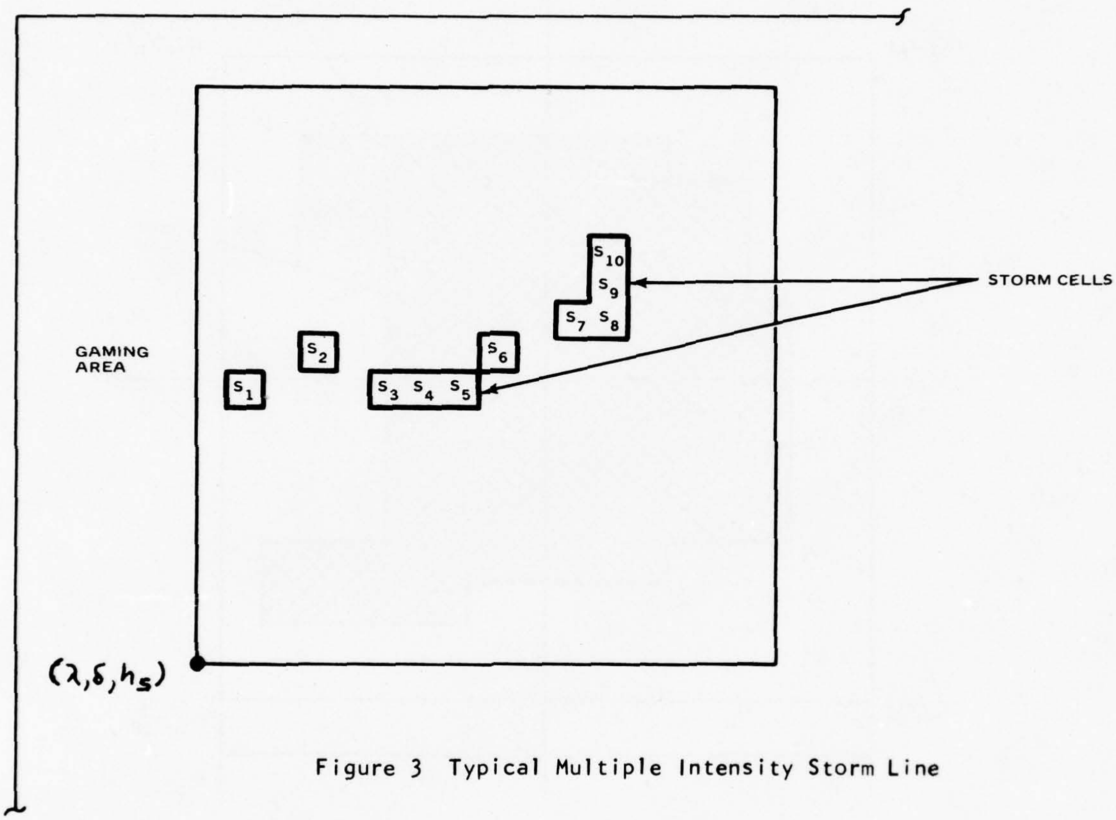

Figure 3 Typical Multiple Intensity Storm Line

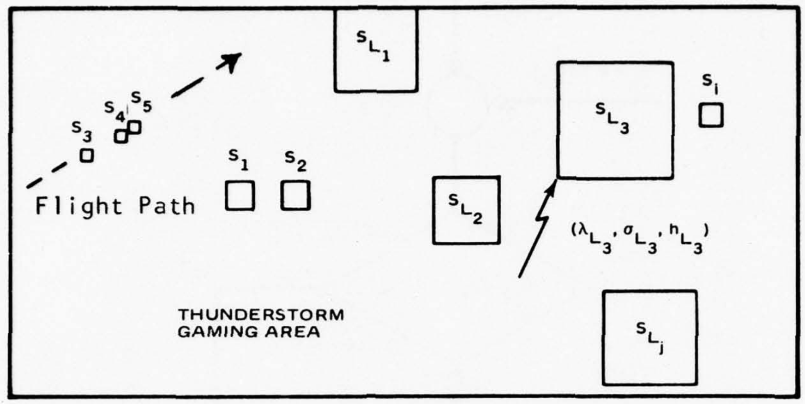

Figure 4 Typical Thunderstorm Gaming Area

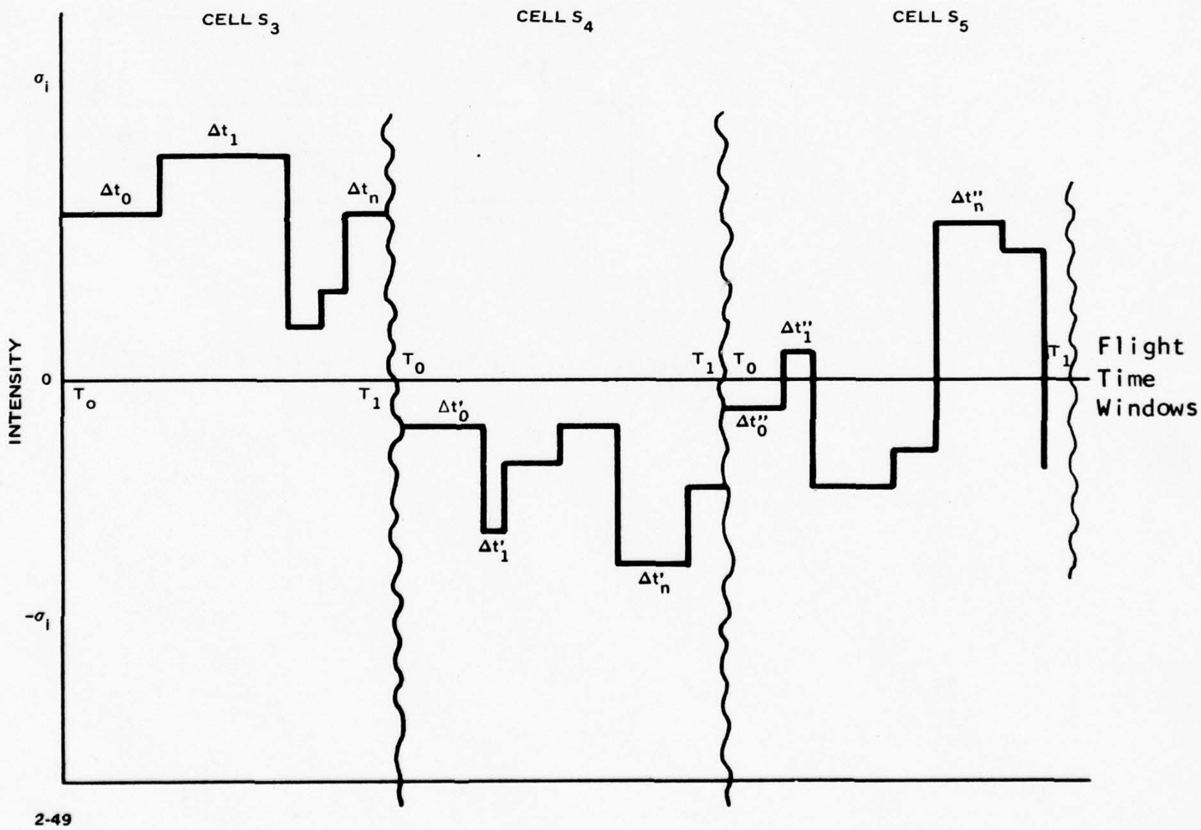

Figure 5 Three Simultaneous Representations of Storm Cell Intensities

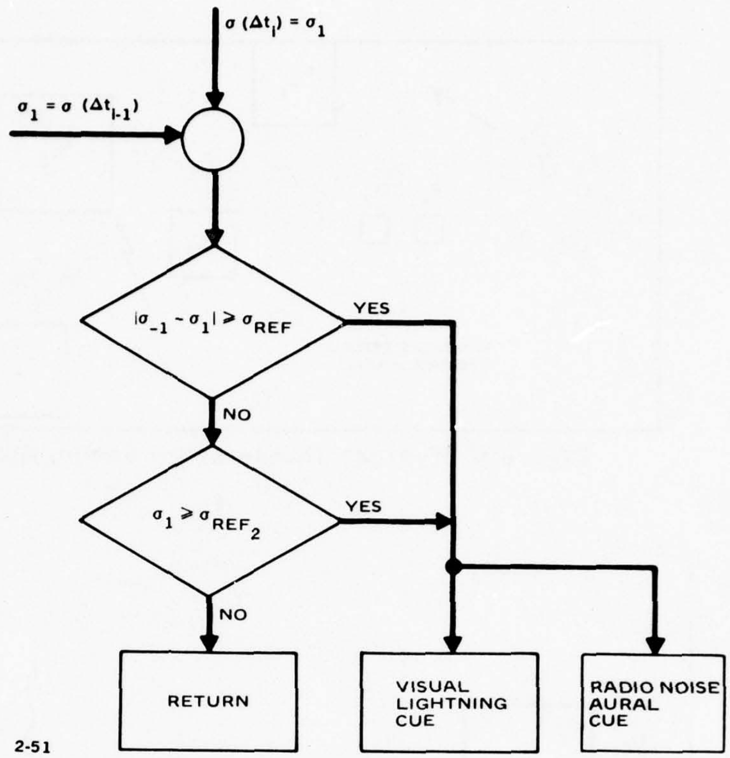

Figure 6 Lightning and Aural Cue Simulation

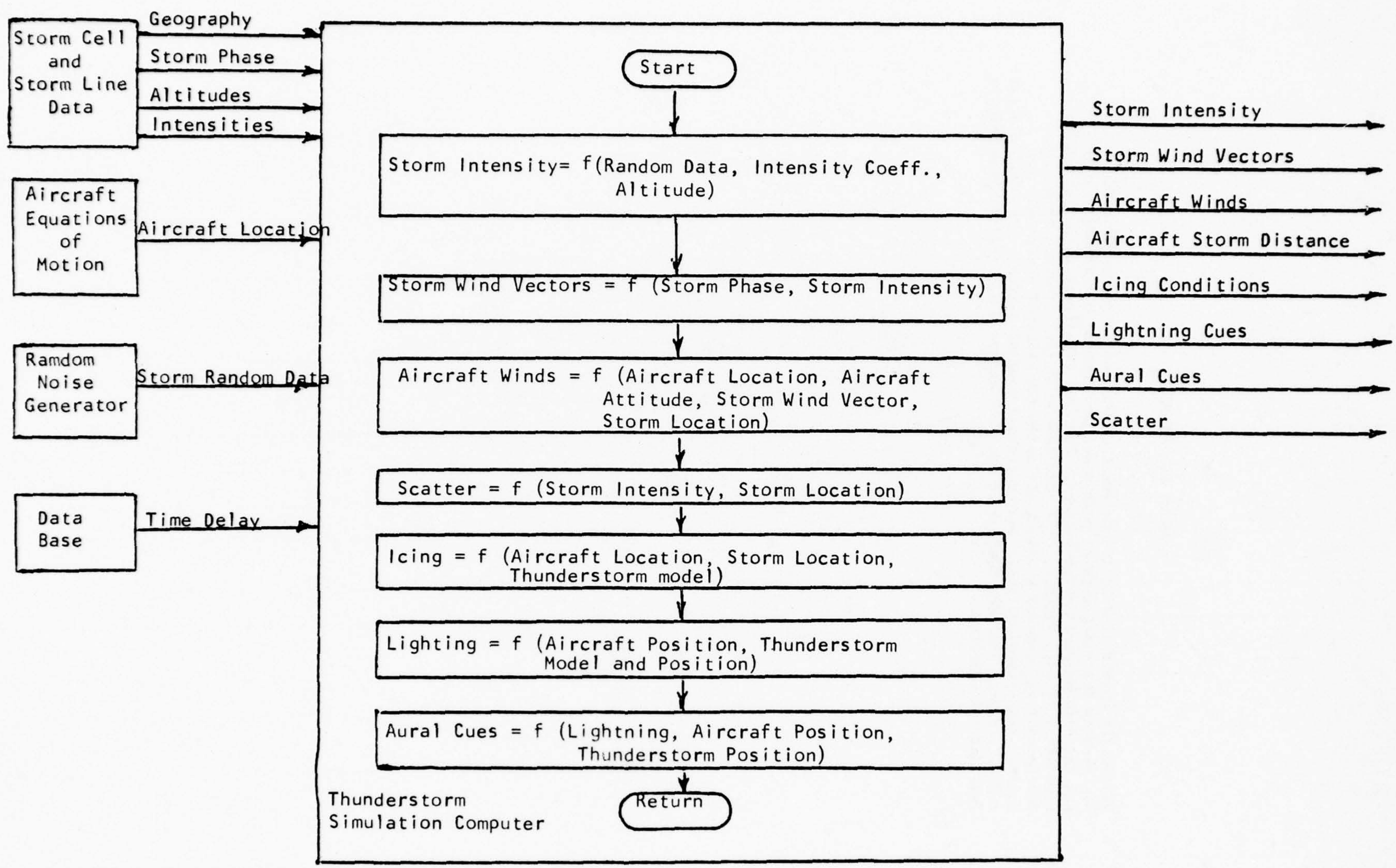

Figure 7

Thunderstorm Simulation Block Diagram

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STIMULATION, NOT SIMULATION: AN UPDATE OF IN-THE-FLEET TRAINING

J. WHITNEY and T. ATHNOS
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SUMMARY

Training in the art of Anti-Submarine Warfare (ASW) in the U.S. Navy has not been totally neglected. Yet, neither has it been conducted with sufficient frequency to produce highly skilled ASW attack teams able to cope with today's major threat: the Soviet submarine force. ASW is mainly a time-consuming matter of attrition, in which numbers count more as friendly losses mount. Some authorities conclude that the U.S., at most, *might sink 10 percent of all Soviet submarines* before they took a serious toll among merchantmen.

The U.S. Navy's active submarine force, as recently as February, 1977, was out-numbered by the Soviet active submarine force 322 to 114. This quantitative shortage could prove crucial in a showdown with the Soviet Union, since "many-on-one" seems to be Moscow's rule. Although ASW missions are shared between surface, subsurface, and air platforms, and the U.S. holds qualitative superiority, U.S. attack submarines face distinct disadvantages trying to check three times their number.

The skill level of ASW attack teams needs to be improved. Accomplishment of this goal can be met by training and subsequently verified by assessment. These methods have been used in the past but not to a level sufficient to produce experts. The Navy has provided simulators and stimulators both in the Fleet (incorporated into or adjunct to the operational equipment) and in shore-based training facilities. Realism has been lacking.

Realism in ASW training does exist albeit infrequently. Submarine services to the surface force are scheduled on a not-to-interfere basis with operational necessities. A further problem lies in the fact that scheduling must be accomplished across lines of operational control; e.g., COMNAVSURFLANT and COMSUBLANT. Submarine services for another submarine are much easier to schedule since a Submarine Squadron Commander may order two or more of his boats to conduct Inter-Ship Exercises (ISE). This scheduling can be accomplished with little or no need for Type Commander interaction.

Other means of realistic training occur when encountering targets of opportunity. Granted,

TABLE 1. US/USSR SUBMARINE FORCES (FEBRUARY 1977)

U.S.				USSR			
TYPE	A	B	C	TYPE	A	B	C
SSBN	39	6		SSBN	62	6	
SSN	65	27	2	SSB	22		
SS	10			SSGN	41	2	
SG			1	SSG	28		
				SSN	39	2	
				SS	130	2	100+
	114	33	3		322	12	100+
	150				434+		

A - ACTIVE

B - UNDER CONSTRUCTION

C - RESERVE

exercise weapons cannot be launched but detection, tracking, and attack solution procedures can be exercised. Oftentimes a ship's mission precludes the opportunity to conduct meaningful training when chancing on these targets.

Operational Readiness Inspections (ORI) are conducted on all U.S. Navy combatants and auxiliaries. Among other facets, these ORI's are designed to assess the readiness of the ship for ASW. The surface Fleet's ORI's are conducted at such places as Guantanamo Bay, Cuba (GITMO), San Diego, and even overseas. Again, the availability of submarine services is a limiting factor in the assessment of ASW readiness. It is not uncommon for a ship to satisfactorily complete the ASW section of the ORI having had no sonar contact on a real submarine. The author is aware of at least one Chief Sonar Technician with 12 years of Fleet experience who has yet to observe a submarine contact on his sonar equipment.

Another requirement mandated by COMNAVSURFLANT is that all AN/SQR-17 Passive Sonar Operators complete 20 hours of training per month. Presently, due to the lack of submarine services and, as necessitated by the equipment, a lack of air services to provide sonobuoys and data links, the training consists of "publication-reviewing" and use of the "Roof-Top Trainer." The latter device lacks real-time, quantitative assessment methods, must be used while in-port, and provides unrealistic submarine data.

This paper will present a training and assessment program designed and developed by General Physics Corporation to overcome deficiencies in ASW training.

BACKGROUND

ASW training using simulators and stimulators was recognized as necessary only 20 years ago. Then, as now, submarine services to provide realistic ASW training to surface ships was conducted infrequently. Tracking targets of opportunity and practicing attack solution procedures on them were the only means by which a surface ship could maintain peak efficiency. Most sonar equipments prior to 1960 had no means by which to be stimulated with simulated target signals.

Classification of sonar contacts can be accomplished accurately only by experienced personnel. Training in this subject is essentially a matter of rote learning. Audio tapes furnish aural data on the various types of underwater targets. Examples are kelp, marine life, pinnacles, torpedoes, and various types of diesel and nuclear submarines. Visual classification training incorporates photographs of targets at various aspects and speeds as presented on the sonar display. Again, memorization is required. The Performance Monitoring Equipment (PME), used in conjunction with later models of the AN/SQS-23 Sonar, is the only stimulator which provides realistic active sonar training. Using a 96 track tape recorder, raw target data can be inserted into the system to provide classification and tracking training. One deficiency of this system is that most equipment controls must be preset negating training of operators on equipment control manipulation.

Successive active sonars of the AN/SQS-26 series were designed to incorporate Sonar Monitors. These requirements, in addition to monitoring equipment transmit and receive levels, introduce target signals enabling operators to receive limited training in the art of target detection and tracking, and equipment operation. Due to the relatively low-frequency spectrum of these sonars and the methods used to visually display targets, classification is often determined by interpretation of target motion rather than by target shape or target echo quality.

One of the newest of the active sonars is the Independent Variable Depth Sonar (IVDS). This system incorporates a stimulator; however, it is designed to provide stationary target signals for test purposes.

General Physics Corporation has devised a methodology whereby these stimulators can be programmed to provide both target detection and tracking and equipment control manipulation training on a maneuvering target.

APPROACH

Realizing the difficulties encountered by the Fleet with regard to ASW training and assessment, General Physics Corporation considered various methods and approaches to overcome these problems. The final decision was to approach the problem in the following manner:

Use existing on-board equipment (no new hardware).

Use "fixed-track" exercises to provide standardized, quantitative problems for assessment purposes.

Use realistic scenarios and, in the case of passive sonar, real "at-sea" ASW encounter data.

Provide exercises categorized into various levels of complexity for both individual and team training and assessment.

Provide a software-only package which will provide immediate reinforcement.

Develop exercises to incorporate all phases of ASW operation from search and detection to tracking and weapon launch.

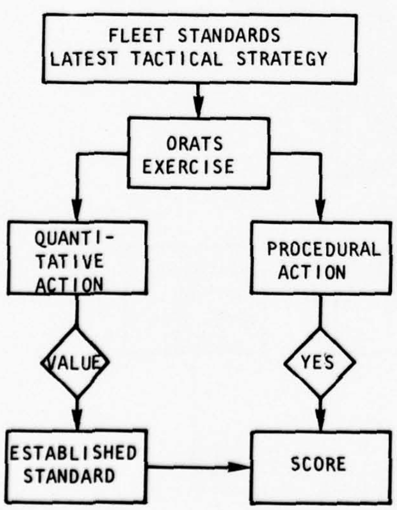

Figure 1. Surface ASW Operational Readiness Assessment and Training (ORATS) System

From these general guidelines, the Surface ASW Operational Readiness Assessment and Training System (ORATS) was developed. ORATS, then, is a program for measuring individual and team performance on realistic operational problems using installed equipment.

Each of the exercises in ORATS can be used by a ship's ASW team for either training or assessment purposes based on the capabilities of ASW personnel.

Positive Guidance — Instructional assistance is provided to the operator(s) as required during the exercise. The exercise can be stopped as necessary to explain concepts and techniques. The exercise is not scored since assistance provided by the Test Director invalidates the results.

Direct Exposure — The exercise is conducted with no assistance from the Test Director. The exercise is usually scored and, using the comments and values recorded during the exercise, thoroughly critiqued indicating to the operator(s) areas of weakness where additional study and practice is required.

Assessment — The exercise is conducted in the same manner as during Direct Exposure. Scoring is mandatory. The assessment method provides commanding officers and operational unit commanders a standardized and quantitative determination of the operational readiness of their crew(s).

Exercise scores have not been normalized, nor are average scores presently available. Scores are meaningful when compared to previous scores of the same exercise or when identifying strong and weak areas of concern.

METHODOLOGY

Surface ASW ORATS is being developed to provide training and assessment for ASW personnel in the Combat Information Center (CIC), Sonar Control, and Underwater Battery (U.B.) Plot. Initially, this system is designed only for the FF-1052 Class Frigate which typically has 2 active sonars, 1 passive sonar, torpedo tubes, and an Anti-Submarine Rocket (ASROC) launcher. Due to weapon and launcher security considerations, all weapon launcher functions are either simulated or a test set is used to stimulate the UB Plot Attack Console.

CIC Exercises (Figure 2.)

Plotting and tracking targets in CIC requires the use of either the NC-2 Plotter or the Dead Reckoning Tracer (DRT). The NC-2 Plotter can be stimulated with own ship and various air, surface and subsurface target data whereas the DRT is stimulated only by own ship motion data. As an option, target data stimulation can be provided aurally by a radar/sonar operator via sound-powered telephones and/or an audio tape cassette.

In a typical CIC Functional Team Exercise (CIC personnel only, with external inputs simulated), an audio tape will provide pre-exercise instructions such as sonobuoy field position, status of LAMPS ASW helicopter and position of assist ship. During the fixed track exercise predetermined own ship and target maneuvers are provided via the audio tape, and LAMPS and assist ship positions on a minute-by-minute basis stimulate the NC-2 Plotter. Assessment (or training) of the Plotter Operator and CIC Evaluator is accomplished by determining the very detailed completeness and accuracy of various plotting, tracking, and target data interpretation functions.

Passive Sonar

The FF-1052 Class Frigate's passive sonar capability accepts actual target data only from sonobuoys via support aircraft radio link. Sonobuoys, each at a different frequency, are launched from an airborne platform, then monitored by that platform. The aircraft selects one or more sonobuoy signals for transmission to the Frigate. Each Frigate is equipped with a 1-inch tape recorder to preserve the data for further analysis.

The General Physics analysts have collected and thoroughly analyzed a series of actual Soviet-U.S. at-sea encounters. These recordings, used to stimulate the Frigate's passive sonar during ORATS exercises, provide one of the few realistic, nonsimulated training and assessment programs available to the Fleet.

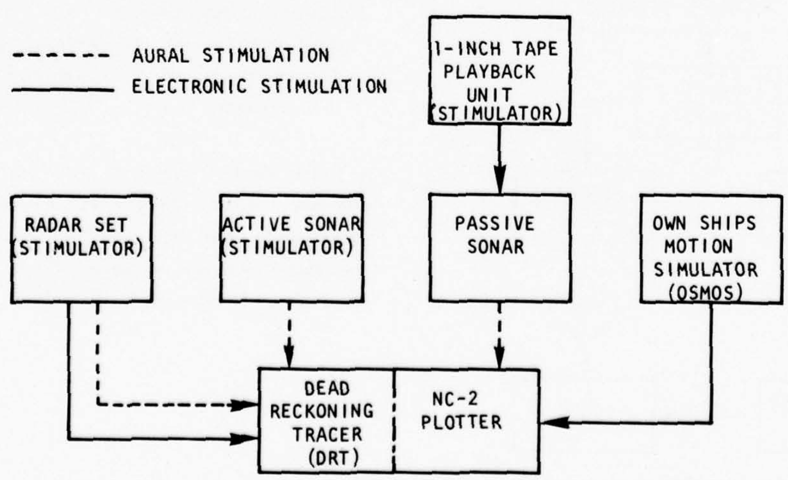

Figure 2. CIC Exercise Equipment Lineup

Passive sonar used onboard surface ships is relatively new. Therefore, some operational doctrine is non-existent. Equipment setup and communication procedures vary from ship to ship. The purpose of ORATS as it relates to passive sonar training is not to set doctrine, but to provide procedures the Passive Sonar Operator can use to enable him to detect more targets, classify targets more accurately, and provide more relevant information such as tactical clues to the CIC Evaluator.

A typical passive sonar exercise begins by informing the operator of the threat type (e.g., possible Soviet Type II nuclear submarine) and threat level. The 1-inch tape stimulates the equipment, providing realistic target data. The operator is required to identify the frequencies emanating from the threat, closest points of approach (CPA's) to various sonobuoys, threat course and speed, and threat classification. He is also required to provide useable and relevant information to the CIC Evaluator.

Active Sonar (Figure 3.)

The AN/SQS-26CX Sonar System is installed on all FF-1052 Class Frigates. The AN/SQS-35(V) system, an Independent Variable Depth Sonar (IVDS), is installed on most of this class Frigate. The content of the ORATS System is determined by ship class; however, those ships not having the IVDS System will still be able to use all but two exercises.

Each of the active sonars incorporates a target simulator. These units can simulate own ship's movement in addition to a single target. Again,

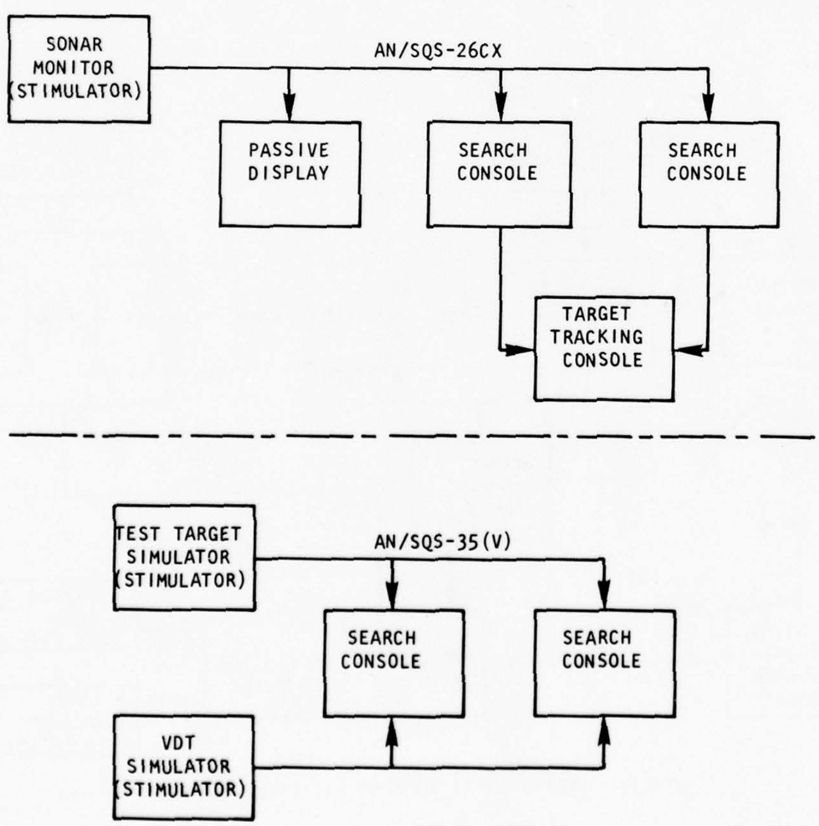

Figure 3. Active Sonar Exercise Equipment Lineup

fixed track exercises are used to cause stimulation of sonar search and track consoles. Targets can be maneuvered to simulate movement of actual targets and can be positioned to require the operators to use the various available equipment operating modes.

A typical ORATS exercise to train or assess a functional team (one or both sonars) provides a target at long range. The Search Console Operator is required to detect the target and manipulate equipment controls to enable the Target Tracking Console Operator to assume tracking responsibility. The Sonar Supervisor oversees these actions and, in addition, is required to interpret and report target data in accordance with standard doctrine. The Test Director simulates responses from stations external to Sonar Control. The Search Console Operator is not required to determine target classification since the signal which stimulates his equipment is qualitatively unrealistic.

Underwater Battery (U.B.) Plot (Figure 4.)

Training and assessment of UB Plot personnel must be conducted in concert with training and assessment of Active Sonar personnel. With regard to target data, the Underwater Battery Fire Control System (UBFCS) can be stimulated only by sonar or radar inputs. Weapon and launcher test sets will provide UBFCS stimuli which provide weapon and launcher status indications.

The function of the UBFCS is to receive raw target data from either of the active sonars or a fire control radar. These data are presented such that an operator can determine target's course and speed. When a weapon and launcher are selected, the UBFCS solves the ballistic computations and remotely controls the weapon and launcher for optimum firing time and aim point.

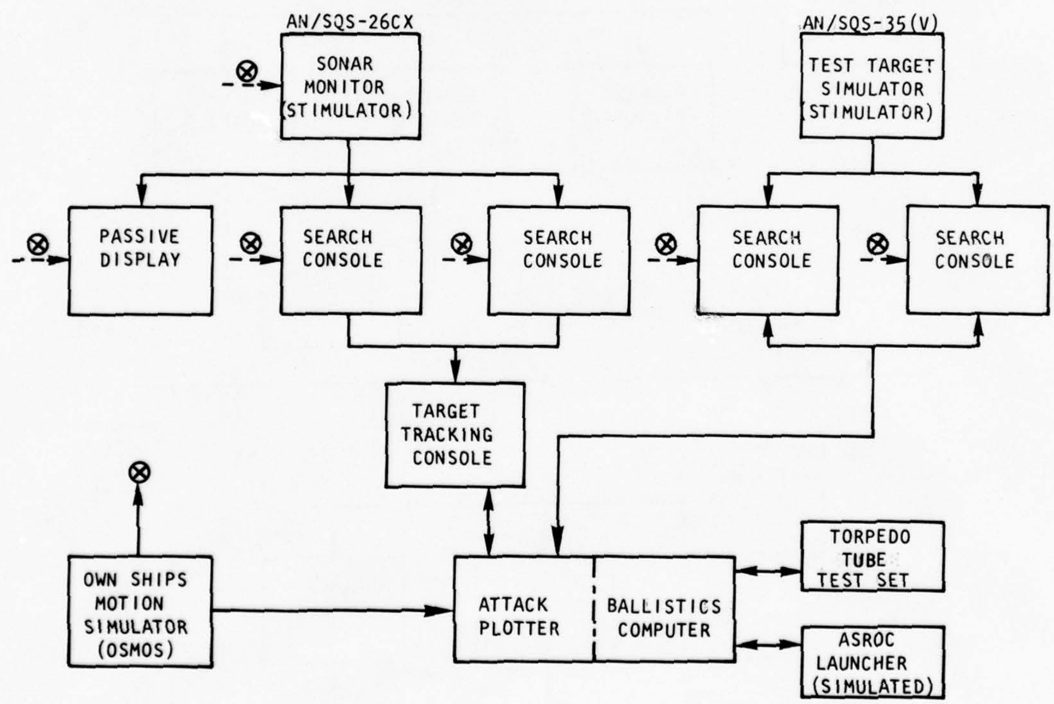

Figure 4. Active Sonar/UB Plot Exercise Equipment Lineup

As previously discussed, weapon security considerations preclude use of the ASROC launcher and even the associated test set which can stimulate the UBFCS. Exercises calling for ASROC launches are conducted by requiring the Test Director to make announcements simulating ASROC launcher and weapon indicator responses. Simulated torpedo tube attacks can be conducted as above or by using a test set to stimulate the UBFCS weapon and launcher indicators. The latter method is preferred but often requires excessive labor to unload the torpedo tubes in addition to requiring the presence of three additional personnel to run the exercise.

A typical Combined Skill Team exercise trains or assesses both the active sonar, as described previously, and the UB Plot personnel. UB Plot personnel training and assessment is based on their ability to properly operate the UBFCS equipment, accurately interpret target data, select proper weapons and launchers, and conduct an accurate and timely attack. Communications between stations, some of which are simulated, is also an important factor which is considered in scoring of the exercise.

The four ASW stations described above always work together when prosecuting a real target. However, seldom do all stations have the same degree of expertise. To counter this disparity, ORATS has been designed to provide training or assessment of individual operators, separate functional teams, various combinations of functional teams, or the entire ASW attack team.

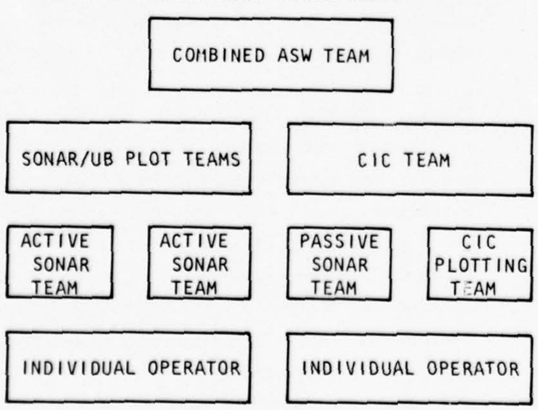

Figure 5. ORATS Program Structure

The Surface ASW ORATS Program for the FF-1052 Class Frigate is comprised of three sets, each consisting of 25 exercises. Four levels of complexity are designed into the Program.

Level I – Combined ASW Team
(1 exercise per set)

The combined Sonar/UB Plot and CIC Teams interact to prosecute simulated submarine targets in a realistic, operational scenario. Level I exercises involve all functional skills using all equipment. It takes about 2 hours to run this exercise.

Level II – Combined Skill Team
(4 CIC exercises per set)
(2 Active Sonar/UB Plot exercises per set)

The Sonar/UB Plot Team or the CIC Team individually prosecutes simulated submarine targets in a realistic, operational scenario. Stations not manned are simulated by the Test Director. These typically take 1 to 1½ hours, including scoring and critique.

Level III – Functional Team
(2 CIC exercises per set)
(2 Active Sonar exercises per set)
(1 Passive Sonar exercise per set)

A specific Sonar Team or the CIC Team is exercised during prosecution of a simulated submarine target. Only the equipments required for the skill being evaluated are used. External stations not manned are simulated by the Test Director. These take about 1 hour.

Level IV – Individual Skill
(7 CIC exercises per set)
(4 Active Sonar exercises per set)
(2 Passive Sonar exercises per set)

Individual operators are evaluated with regard to specific skills on a particular equipment or unit of a system. These take about 45 minutes to an hour.

TAPES

- AUDIO CASSETTE EXERCISE INSTRUCTIONS AND NARRATIVES
- 1-INCH PASSIVE SONAR DATA TAPE

TEXTS

- VOLUME I PROGRAM MANUAL
- VOLUME II CIC EXERCISES
- VOLUME III PASSIVE SONAR EXERCISES
- VOLUME IV ACTIVE SONAR EXERCISES
- VOLUME V ACTIVE SONAR EXERCISES

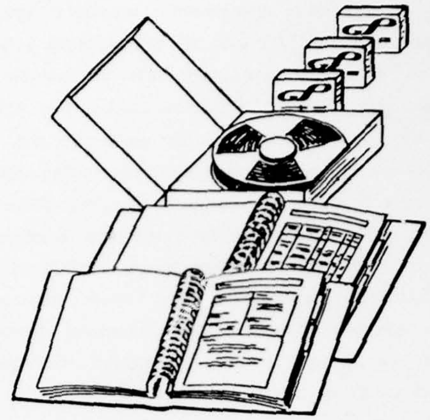

Figure 6. ORATS Program Package

SOFTWARE FORMAT

General

The ORATS Program delivered to the ship consists of five looseleaf binders, one 1-inch tape for the Passive Sonar recorder-playback device, and 17 audio cassette tapes. Stopwatches and a cassette tape playback device must be furnished by each ship to enable them to run any ORATS exercise.

Volume I, Program Manual, designed for the ship's Training Officer, contains introductory material and a Selection Index summarizing all exercises in the set. This volume is unclassified.

Volume II, CIC Exercises, designed for the Operations Department, contains all Level II through Level IV CIC exercises and the Level I Combined ASW Team exercise. This volume is classified Secret.

Volume III, Passive Sonar Exercises, designed for the Weapons Department, contains all Level III and IV passive sonar exercises. This volume is also classified Secret.

Volumes IV and V, Active Sonar and Combined Active Sonar/UB Plot Exercises, also designed for the Weapons Department, contain all Level II through IV Active Sonar and Combined Active Sonar/UB Plot exercises. These volumes are classified Confidential.

The 1-inch Passive Sonar tape is classified Secret, as are about half of the audio cassette tapes. The remainder of the cassette tapes are classified Confidential.

Exercise Format

Each ORATS exercise is divided into five basic sections.

Content Sheet — The first page of each exercise provides a combination index/list of effective pages which is required for classified material. A very brief summary of pre-exercise requirements is also presented which lists essential equipment.

Exercise Summary — This section provides an abstract, a brief scenario, a list of equipment and personnel required, exercise time, the basis of evaluation, and a chronological summary of events including a track chart plot. (Figure 7.)

Procedure — The Test Director uses this section to conduct and oversee the progress of the exercise. The Procedures describe switch line-ups, equipment connections, and specific actions to be accomplished by the Test Director, the Observers and the personnel being evaluated on a minute-by-minute basis. It provides specific evaluation instructions including quantitative performance standards, standardized checkpoints and space to record data and score the results. (Figure 8.)

TEST SUMMARY | **TEST NUMBER** 111S-2

TITLE
FUNCTIONAL TEAM TEST
SONAR-ACTIVE-AN/SQS-35(V)

PURPOSE To test the overall ability of the AN/SQS-35(V) Sonar Team to detect, classify and track various simulated submarine and non-submarine maneuvering targets.

ABSTRACT The AN/SQS-35(V) Sonar Team conducts search and tracking operations on various simulated targets. Environmental data is provided to enable the Sonar Supervisor to determine range predictions. Targets are generated by the Test Target Simulator.

TIME
40 minutes

PERSONNEL Test Director, Sonar Supervisor, Sonar Operators (2), Test Target Simulator Operator.

EQUIPMENT AN/SQS-35(V) Sonar System including Units 13 and 16. 2 stopwatches.

LOCATION
Inport or Underway

PRESENTATION SUMMARY

Own ship is underway in the Mediterranean during peacetime. The Variable Depth Transducer is streamed and a standard Condition IV search is being maintained. Simulated targets available for detection include a submarine, a merchant vessel and a pinnacle.

All display consoles will be used. The Sonar Supervisor will be assessed on his ability to direct the interaction of the Operators, select optimum search and track parameters, and properly classify each target.

EVALUATION Based on target detection, equipment operation procedures, identification of target maneuvers, tracking accuracy, information flow and calculation of Sonar Performance Predictions.

PAGE NUMBER TS-1

TEST SUMMARY | **TEST NUMBER** 111S-2

TITLE
FUNCTIONAL TEAM TEST
SONAR-ACTIVE-AN/SQS-35(V)

PRESENTATION DETAILS

Time (hr:min:sec)	Event
0:00:00	Own ship initial parameters: Course 000 Speed 10 knots Target (submarine) initial parameters: Course 240 Speed 5 knots Range xxxx yards Bearing 090 T.
0:01:00	Target (submarine) detectable.
0:05:00	Own ship changes course right to 090.
0:08:00	Target (submarine) changes course left to 160 and increases speed to 15 knots.
0:10:00	Target (submarine) dives below layer.
0:12:00	Target (submarine) evades own ship. Contact is lost.
0:14:00	Own ship changes course left to 045.
0:15:00	Target (merchant vessel) detectable. Course 080 Speed 12 knots Range xxxx yards Bearing 270 T.

PAGE NUMBER TS-2

Figure 7. Exercise Summary (example)

TEST PROCEDURE	TEST NUMBER IIIS-2

TITLE FUNCTIONAL TEAM TEST
SONAR-ACTIVE-AN/SQS-35(V)

Time hr:min:sec	Test Instructions	Data	Evaluation Guide	Ref
0:32:00	TEST DIRECTOR: Announce, "All stations, Bridge. We are coming left with standard rudder to course 335 and increasing speed to 15 knots."			
0:32:00	TEST TARGET SIMULATOR OPERATOR: Make the following settings: Own Ship's course left to 335 at a rate of 2 degrees per second. Own Ship's speed to 15 knots.			
0:33:00	TEST DIRECTOR:			
	Does the Sonar Supervisor direct the Operators to search sector 180 to 270?	____	Yes	2 A
	Does the Unit 1 Operator select SCAN RECEIVER?	____	Yes	2 B
	Does the Unit 2 Operator select maximum range scale?	____	Yes	2 C
0:34:00	TEST DIRECTOR:			
	Does the Unit 1 Operator detect the target?	____	Yes	1 B
	By time 0:34:00?	____	Yes	1 B
	Does the Unit 1 Operator report:			
	Target detection to the Sonar Supervisor?	____	Yes	1 D
	Bearing drift?	____	Left	1 D
	Range drift?	____	Closing	1 D
	Target Doppler?	____	Slight up	1 D

PAGE NUMBER	TP-20

Figure 8. Procedure (example)

TEST RESULTS SUMMARY	TEST NUMBER IIIS-2

TITLE

FUNCTIONAL TEAM TEST
SONAR-ACTIVE-AN/SQS-35(V)

INDIVIDUAL/TEAM NAME(S)	DATE
	TEST DIRECTOR
	TEST OBSERVERS/OPERATORS

RESULTS SUMMARY

Group	Subject	Possible	Score	%
A	Sonar Supervisor Procedures	90		
B	Unit 1 Operator Procedures	70		
C	Unit 2 Operator Procedures	80		
D	Information Flow	30		
E	Unit 1 Tracking Accuracy	40		
F	Unit 2 Tracking Accuracy	40		
G	Sonar Performance Predictions	50		
	TOTAL	400		

NOTES

PAGE NUMBER	TRS-1

Figure 9. Test Results Summary (example)

Test Result Summary — A categorized summary by function of points scored during the exercise is recorded in this section then compared to the maximum score possible. The resultant percentage of each category can be used as a means to determine areas of weakness in which further training is required. Scores have not been normalized nor is there any basis from which a pass/fail grade can be determined. As these exercises are used, the Fleet percentile will be obtained, thereby enabling evaluators to better measure team and individual ability. This unclassified section can be used for inclusion in department training records. (Figure 9.)

Appendices — Each Observer is furnished an exercise appendix which provides data extracted from the Procedure section. Format and use is identical to the Procedure; however, only those sections of the Procedure pertaining to that particular Observer is included. Other appendices provide such information as tactical and environmental data, equipment transmission checks (which ensure proper alignment), reference notes, and a listing of the Personnel Qualification Standards (PQS) satisfied.

CONCLUSIONS

Surface ASW ORATS evolved from a program developed by General Physics Corporation for the U.S. Navy submarine force: Submarine Operational Readiness Assessment and Training (SORAT) Program. SORAT has proven practical and effective in the training and reinforcement of submariners' ASW skills. Submarine crews are using SORAT for training to prepare for predeployment inspections, tactical weapon certification, and other readiness assessments.

ORATS is presently being implemented on all FF-1052 Class Frigates. On completion of the 16-hour demonstration, ship crews most always respond with plaudits for the Program. Typical responses refer to the need for such a program, its administrative simplicity and all-encompassing assessment of operators and teams, and finally its maintenance-free aspect.

ORATS will, in all probability, be developed for other ship classes, such as the DD-963 Class Destroyer. This class vessel incorporates the Navy Tactical Data System (NTDS) with an ASW program requiring a more complex form of the ORATS Program. Similar work is already under contract for the SSN-688 Class computerized AN/BQQ-5 System. The format will be similar to the FF-1052 Program, yet will include more tactically significant features as mandated by the additional equipments installed.

Investigations are being conducted to determine the feasibility of development of an ORATS-type training program for use by shore-based ASW trainers and an assessment program for use by Refresher Training (ORI) Inspectors. This type program can be developed for most any equipment which has the capability of being stimulated. A similar program has been demonstrated to the Naval Aviation ASW community. Anti-Air Warfare (AAW) Teams are likely candidates for an ORATS training and assessment program. A similar program has been incorporated into computerized simulators. The computer functions as Test Director and Observer, recording and scoring all control manipulations. In this type format, a human Observer would be required only to record nonmechanical operator functions.

Training and assessment practices must be based on objective and quantitative, not subjective and qualitative judgments. Programs must be developed in a cost-effective manner. Stimulating existing equipments when possible is certainly less costly than producing new and more sophisticated simulators. Maintenance and manpower costs must be considered in addition to initial procurement costs. The ORATS Program and its relatives are cost-effective, objective, quantitative, and, above all, effective in the improvement of ASW skills.

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A NEW APPROACH FROM IMPROVING TACTICAL ACTION/REACTION TRAINING AND TACTICAL PROCEDURES DEVELOPMENT USING THE ACTION SPEED TACTICAL TRAINER IN THE GERMAN NAVY

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I. INTRODUCTION

In the late sixties the development of technology for naval warfare came into a dynamic phase by new innovations in the area of electronic warfare as well as by the introduction of surface-to-surface missiles and the resulting need to provide defensive measures against them.

The well-known interdependence of technology and tactics required the adaption of naval warfare to these new technical aspects. The sinking of the Israeli destroyer "Eilath" indicated this very clearly.

The influence on tactics, provoked by progress in technology of sensors and effectors, forced consideration of improved tactical training for officers. Up to that time trainers - operating via an electromechanical system - had been considered to be sufficient for this purpose. But it became evident, that the training devices in their operating concept had to allow for this interdependence.

Within the German Navy, the following tasks are assigned to the Naval Tactical Training Group (NAVTACTNGGP) in Wilhelmshaven:

- Improvement of the tactical training of naval and naval-air-arm officers.
- Establishment of the fundamentals of naval tactics and their further development.
- Research of tactical and operational problems in specific areas of naval warfare which are considered most important for the German Navy.
- Further development of naval tactics concerning the adjustment to the technological progress and formulation of appropriate procedures.

At the above mentioned time period, the NAVTACTNGGP had the Redifon-ASTT in service. This trainer, however, due to its technology, was no longer sufficient to simulate naval warfare actions in a modern, realistic environment. This also meant, that the mission to train officers in tactical decision making was very difficult to accomplish.

The commissioning of the preponderantly software-oriented Singer-ASTT as the replacement of the Redifon-ASTT in March 1976 provided the potential to simulate all aspects of modern naval warfare, to adapt to future technological and tactical developments, and to offer enough flexibility for solving tactical problems.

II. THE STRUCTURE OF THE ASTT

The ASTT consists of commercial equipment delivered by several sub-contractors with Singer-Link as the prime contractor. The prime contractor was held responsible for interfacing components into an integrated, fully operational hardware-software complex.

With respect to the tasks of this simulator it did not appear necessary to adapt the equipment to the combat information centers of the different naval assets, but instead to employ commercial hardware with software developed to simulate each training scenario.

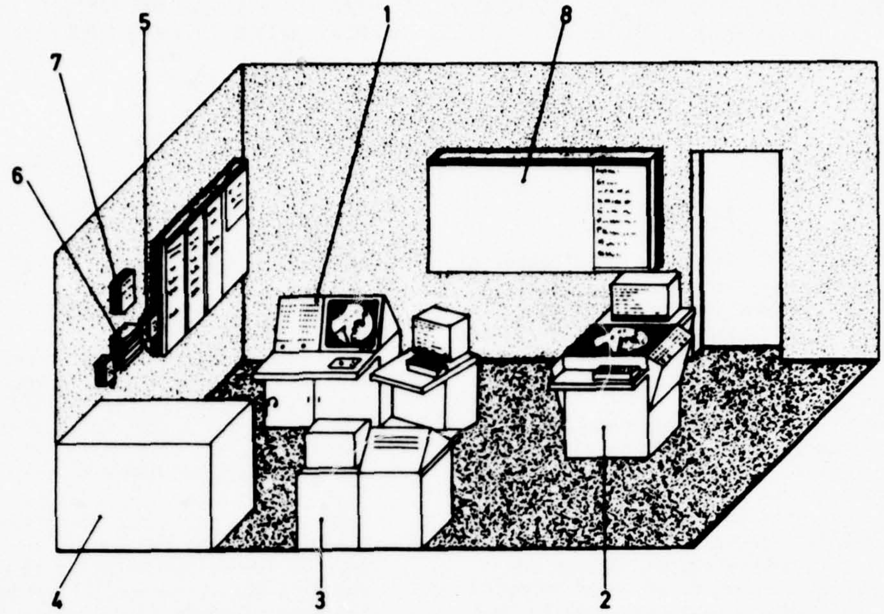
A. EXTENT OF THE HARDWARE

The hardware consists of the following components:

* The nucleus of the simulator are 4 free-programmable computers PDP 11/45 of Digital Equipment Corporation with the necessary peripherals. A total core of 300 K is available; the word-length is 16 bit.

* Each of the 14 cubicles may serve as a submarine, surface ship, or aircraft. They all are alike equipped with a commander's display unit, a horizontal display unit, and a communications console providing external (HF/UHF) and internal communications. An alphanumerical display console supplemented by a keyboard is used as part of each of these units/console. Each cubicle is under direct control of a commanding officer/pilot; two cubicles have an additional horizontal display unit, and can serve as units of the Officer in Tactical Command (OTC). The above mentioned video situation displays present a synthetic air/surface-, and, if appropriate, a subsurface-picture, consequently, there is a combination of all information available by the existent sensors of the respective vehicle.

The display of information - similar to that of the command and control systems of the German destroyers and missile-carrying, fast patrol boats in combination with the picture-compilation via LINK 11 data-transfer in a force - is automatically provided. Navigational details as well as jamming are also simulated on the display.



1 Commander's console
2 Horizontal display console
3 Communication console
4 Chart table
5 Communications
6 ESM indication panel
7 Cubicle data
8 State boards

Figure 1. Cubicle Layout

Each cubicle has a defined track-capacity as a function of its personnel capabilities. Evidently, the minimum capacity is assigned to a fighter aircraft, whereas the maximum capacity is provided for a unit with an automatic command and control system. Different delay times are implemented to simulate the distinct transmission times as a function of the degree of automation.

In addition to the tactical display unit, the alphanumberical display terminal provides much of the essential information necessary to assess the tactical situation; it is used for selecting, controlling, and monitoring a large number of exercise parameters. The information and parameters are displayed in page formats, referred to as tableaus. The standard tableau - see Figure 2 - is divided into five areas as shown below:

- The top three lines contain the cubicle's operating parameters (speed, course, altitude/depth, and position), track number, the current exercise time, and the name and mnemonics of the tableau.
- The left center portion of the tableau is provided for input of new data.
- The center portion of the tableau is provided for information relevant to the data entry area. Readouts of current values of selected data are also provided in this area.
- The right center portion of the tableau is provided for alert messages like "ESM-Contact" and "Missile Hit."
- The lower portion of the tableau is provided for operator data entry.

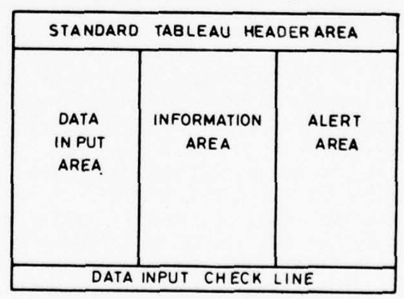


Figure 2. Standard Tableau

It is possible to modify at any time the operating parameters without a change of a tableau.

* A Maritime Headquarter (MHQ) permits the involvement of the operational level and

the respective decision-making processes in exercises. The MHQ also has tactical display units with alphanumberical display terminals. A Vertical Display Plot (VDP) is included in the MHQ. It is a monochrome display which presents an overall situation display. The presentation of information results from LINK 11 or conventional data-transfer by the cubicles.

* An auditorium with a seating capacity for 60 persons also serves for exercise control and a subsequent debriefing. To monitor exercises, seven control consoles are available; each is fitted with a tactical display unit and two alphanumerical display units supplemented by communications equipment.

* A Large Screen Display (LSD) is included in the auditorium; it is a color system which projects an overall view of the tactical situation on a screen, with matched tape recorded exercises.

B. EXTENT OF THE SOFTWARE

As already pointed out, the important difference between this ASTT and the Redifon ASTT is that the trainer's performance results from the inherent capabilities of the software implementation which consists of the:

- operation/simulation program, and the
- training assistance program.

1. The Operation/Simulation Program

This program consists of several modules which control the entire flow of exercise events with all its functions in real-time; in particualar, it controls the vehicles sensors, effectors, communication-systems, their operating parameters, and the environmental conditions, in which they operate. Via the following tableaus the vehicle's capabilities and information necessary for its employment are controlled/directed:

Damages affected by weapon engagements can also be simulated. The program offers the possibility to display, in addition to the 14 cubicles, 112 "synthetic" targets. The program also provides the access to the extensive data base with a collection of characteristics and specifications about vehicles, sensors and effectors.

a. Simulation of Sensors

Each cubicle can dispose of the following sensors in accord with the particular type-/class-definition:

- Radar (up to 4 sets),
- Sonar (up to 3 sets),
- Electronic Support Measures - ESM (up to 2 sets),
- Magnetic Anomality Detection (1 set),
- Sonobuoys (quantity according to the type),
- Infrared Detection (1 set), and
- Tactical air navigation (1 set).

The functions of a particular sensor are simulated only as necessary for tactical decision-finding. For instance, the frequency, the transmission, and the scan-mode, if appropriate, can be selected for each radar set. On the other hand, after the detection of a hostile radar, its band or even the frequency, the bearing accuracy, and the spot number will be displayed on a corresponding tableau as a function of the quality of the utilized ESM-set.

b. Simulation of Effectors

Each cubicle can dispose of the following effectors in accord with the particular type-/class-definition:

- Missiles (up to 3 systems),
- Guns (up to 2 systems),
- Torpedoes (up to 2 systems),
- Rocket torpedoes (1 system),
- Antisubmarine-Warfare rockets (up to 2 systems),

IDX	CUBICLE INDEX		
VEH	VEHICLE CONTROL	SON	SONAR
TGT	TARGET CONTROL	SBY	SONOBUOYS
MTR	MANUAL TRACK	ASI	ASW INFORMATION
IDT	IDENTIFICATION	AAI	ASW AIR INFORMATION
TD 1-4	TARGET DATA	SSN	SPECIAL SENSORS
MNV	MANEUVERS		
REF	REFERENCE POINTS	WPS	WEAPONS SUMMARY
		MIS	MISSILES
RAD	RADAR	GUN	GUNS
COM	CUBICLE COMMUNICATIONS	TOR	TORPEDOES
RAT	RATT COMMUNICATIONS	AWP	ASW WEAPONS
ESM	ELECTRONIC SUPPORT MEASURES	AIR	AIR WEAPONS
EEI	EW/ESW INFORMATION		
RKT	RACKET DATA	DMG	DAMAGE ASSESSMENT
ECM	ELECTRONIC COUNTERMEASURES		

Figure 3. List of Tableaus

- Depth-charges (quantity according to the type),
- Bombs (quantity according to the type),
- Electronic Countermeasures - ECM - (up to 2 jammers and chaff-quantity according to the type).

For instance, the model for the missile employment provides the following features:

- Selection of the appropriate system (SSM, SAM),
- Readiness to launch the missile(s) not till correct insertion of relevant data and target in range, and open arcs,
- Selection of search-parameters,
- Target acquisition if a target within search-area, and
- Reduction of hit-probability if missile is subject to adequate ECM by the target.

This simulation model comprises all essential criteria which are substantial for the actual missile employment, and therefore also significant for the tactical training at the ASTT. Figure 4. shows the relevant tableau. Similar features are provided for the other effector types, if appropriate. The instructor is able to intervene to prevent a hit or to enforce one, based on data information only available to him.

c. Simulation of Communication Systems

The ASTT is equipped with 3 different types of communication systems, namely, the simulation of

- Automatic/Semiautomatic data transfer (LINK 11/14),
- Radio teletype (RATT) communications, and
- Voice communications.

The systems are also activated according to the particular type definition.

d. Simulation of Damages

This part of the program simulates the effect of weapons employed to carry on tactical exercises under realistic combat situations during the engagement phase. Inflicted damages are determined by a random number generator as a function of the employed weapon and attack unit. If the instructor does not override such a damage message by an appropriate input, the indicated damaged systems of the affected vehicle are automatically turned off or modified: even a total loss is possible.

MIS MISSILES	TN 1400	21 53 20
2 COURSE: 280 (280) DEGR		XPOS 5120
3 SPEED: 0020 (0020) KTS		YPOS 5120
5 MISSILE SYSTEM: 3 (1-3)	MISSILE SYSTEM SSM	
SYSTEM 1	MISSILES AVAILABLE 04	
2	MAX. RANGE 40 NM	
3	MIN. RANGE 5 NM	
9 TARGET TN: 8040 OR	GUIDANCE	
10 BEARING:	MIDCOURSE	
11 DISTANCE: YDS	TERMINAL	
13 LAUNCHER NO: 1,2	LAUNCHERS 4	
14 MISSILES TO FIRE: 2	1 OR 2	
15 FC RADAR: 1	0=OFF, 1=ON	
16 MIDCOURSE HEIGHT: 1	1=0050, 2=0050, 3=0050 (YDS)	
17 TERMINAL HEIGHT: 1	1=0010, 2=0015, 3=0025 (YDS)	
SETTING TERMINAL HOMING		
19 SEARCH WINDOW: 2	1=WIDE, 2=NORMAL, 3=NARROW	
20 AZIMUTH: 2	1=010, 2=015, 3=025 (DEG)	
21 RANGE GATE: 2	1=02000, 2=05000, 3=09000 (YDS)	
22 ACTIVATION RANGE: 2	1=08000, 2=16000, 3=21500 (YDS)	
READY		
25 FIRE: 0	1=FIRE, 2=UNLOAD	
LINE 25 DATA 1		

Figure 4. Missile Tableau

e. Simulation of the Environmental Conditions

The effectiveness of the employment of sensors, effectors, and communication systems is influenced by the environmental conditions in the operation area. This consideration can have a cogent impact on the tactical decision-finding process; therefore, the following conditions are taken into account for the simulation:

- Wind (direction/speed),
- Current (direction/speed),
- Radar-weather,
- UHF-weather,
- Sonar-propagation,
- Layer-depth,
- Optical range,
- Infrared range.

These conditions are implemented as factors which degrade or enhance the system performance.

f. Simulation of Targets

A realistic simulation of naval warfare requires more participants/targets than just 14; therefore,the number of cubicles/vehicles/targets was extended by an additional 112 "synthetic" targets. Like all cubicles, these targets can, at discretion, be defined as submarines, surface vessels, or aircraft, and, supplementarily, they may serve as missiles, torpedoes, chaff, or false targets due to jamming. Targets presently not needed are on standby in a so-called "pool" and may be used when required by the scenario; 30 of these targets with respect to the particular vehicle definition have a limited number of

Sensors - Radar and Sonar -, and

Effectors - Missiles, Guns, Torpedoes, Jammers, and Chaff - available.

The targets are controlled by the instructors, the cubicles or by a special program.

2. The Training Assistance Program

This program serves as a supporting program for automated tactical exercises to control the flow of events. This program may assume the following tasks:

- To call the attention of the instructor at the control console to observe events or their development thus relieving him of routine workload.
- To control selected exercise parts by pre-defined criteria which, for example, will permit computer control of individual targets or an entire party.
- To enable simultaneous conduct of several minor exercises separate from each other.

The following figure shows as a summary the general layout of the ASTT concerning the hard-and software.

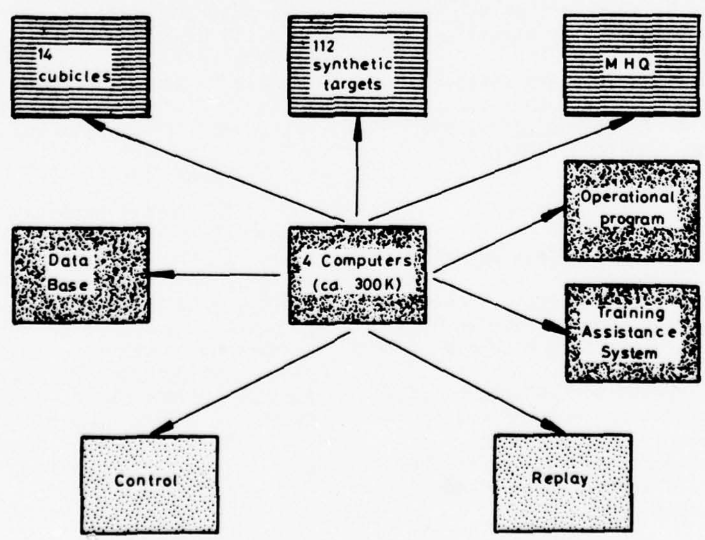


Figure 5. General Layout of ASTT

III. VALUE OF THE ASTT FOR TACTICAL TRAINING

The substantially improved capabilities of the Singer-ASTT in comparison with the Redifon-ASTT, and consequently the value of this modern simulator for the tactical training are best expressed by to the following criteria.

A. REALISM

Each vehicle type, even different versions of one class, can be defined individually. Steaming characteristics, sensor and weapon employment largely reflect actual conditions.

The danger of obtaining too good information from the computer was averted by reducing factors.

Generally, all technical possibilities that might influence the tactical posture are simulated in a realistic way. Thus, artificialities in training are minimized, the results are realistic.

The large number of targets provides the possibility to simulate each aspect of a threat in all three dimensions.

B. VERSATILITY

The trainer offers a wide spectrum of applicability for meeting various training requirements. Simulation is possible at all tactical levels, from simple tactical procedural exercises through complicated tactical situations to war games including the operational level MHQ.

Exercises may be conducted as one-, two- or multiple-party games. Parties may be posed by cubicles, that is by students, or by "synthetic" targets which are either manually- or program-controlled.

The free programmability and optional data selection almost guarantee that the trainer can be adapted to technological and tactical developments and thus remain up to date.

C. EFFECTIVITY

The trainer ensures an effective and especially economic training.

In contrast to live exercises, simulated exercise sequences permit creation of a magnitude of decision situations within a relatively brief period of time.

Mistakes are permitted. The effects of a wrong tactical decision can be exercised in the trainer. Situations can be repeated, specific actions can be initiated to test reactions. This will aid in evoking decision readiness and self-confidence.

Situations that cannot actually be established for reasons of costs or security, such as weapon employment and weapon effect, can be simulated at the ASTT. Precisely, it is the inclusion of weapon effect into the simulation which conspicuously shows tactically correct behaviour or wrong decisions; this aspect of training can be covered by nothing better than by a simulated scenario.

The trainer is capable of simultaneous control of several minor exercises separate from each other, which permits, for example, separation of portions from a major exercise and their cubicle-wise or group-wise drill in advance of the actual exercise.

D. TRANSPARENCY

Program control of functions minimizes inadvertent intervention by the instructor for example, as a result of different reactions in an identical situation. On the other hand, all functions can, at any time, be monitored by the instructor and controlled by his intervention. Pertinent information required is available to the controlling staff. If necessary, an exercise can be discontinued and resumed at an earlier moment.

E. SIMPLICITY OF OPERATION

The multitude of functions and capabilities inherent in the ASTT requires an extensive operation section. By use of programmed familiarization - simulataneously conducted in all cubicles -, it is possible to acquaint students with operating the trainer in its functions within a relatively short time. This task is facilitated by a homogeneous, centralized operating concept. In order to fully exploit all capabilities inherent in the trainer, an assistant is assigned to each cubicle to support the relevant command team, especially by operating the commander's alphanumerical display console.

F. REPLAY OF EXERCISES

The debriefing as a very important component of an exercise will be supplemented and shaped by the replay of the respective simulated operation presented on the "Large Screen Display." Each optional exercise time - forward or backward - can be called up; the complete scenario or section can be displayed with a scale varying from 25 x 25 up to 1000 x 1000 nautical miles. The flow of exercise events may be in a time compression mode,if required.

The student also benefits by these capabilities; he can consummate the essential

sections of the exercise afterwards, and he becomes aware of tactically clear-sighted or thoughtless and ill-advised decisions. The debriefing as the dialogue between the instructors and the students is condensed to the discussion of tactical facts of the operation.

IV. VALUE OF THE ASTT FOR TACTICAL DEVELOPMENT

The Singer-ASTT offers the potential to accomplish tasks which were unfeasible with the Redifon-ASTT; these tasks had been aspects of naval warfare which otherwise would have required considerable expenditures in costs, time and personnel. Artificialities which are imposed by safety-regulations and civilian traffic would detoriate most results concerning naval tactics without the possibility of replays. It is well known that general tactical solutions can never be derived from one life-exercises only. The following applications grant the value of the simulator for the complexity of tactical development:

- Preparation and replay of tactical exercises. The solutions found may be varied by repetition with modified parameters, for example, in the initial situation or in decision situations. This would permit the selection of an optimum solution.
- Evaluation of tactical exercises and comparative evaluation of diversified solutions. Exercise sequence may be tape-recorded and replayed when required.
- Development of employment concepts for new weapon systems. By simple parameter modification or supplementation, any desired vehicle can be simulated. Such a simulation with its account for reality allows qualitative conclusions.
- Extensive tests of projected new tactics or weapon systems in the simulator prior to contract award.
- Conduct of tactical simulations with operations research methods, supported by the extensive computer system.

V. IMPACT ON THE UTILIZATION OF THE ASTT AND ITS LIMITATIONS

The multiplicity of the functions and the potential of the utilization of the Singer-ASTT as well as the extensive hard- and software presented a considerable impact on the utilization, and, therefore, required a new concept for its operation:

- Special knowledge in the fields of programming and computer techniques is indispensable.
- An extensive data file must be established and continuously complemented.
- To operate the system, it is imperative for operating personnel to acquire special knowledge and go through relatively long familiarization times.
- For preparation of exercises, tactical /operational requirements are to be converted into system-specific requirements.
- Programs for control of specific exercise cycles are to be defined and developed.
- There will hardly be any idle times for the trainer, since, in addition to tactical exercises, maintentance and programming also call for system operation.

The limitations of the ASTT primarily result from the simulation itself. All simulations have their constraints inherent in the definition of the problem to be studied/analysed, and in the artificiality of the conduct of the simulation which has its origin in technological facts.

There must be a compromise between the results which the naval officer wants to obtain by a simulation, and the extent of programming which the programmer can offer in the frame of the availabe soft- and hardware; a simulation sometimes only approaches reality.

VI. SUMMARY

The Singer-ASTT of the NAVTACTNGGP is a versatile and modern simulator which renders an effective and realistic training in naval tactics. Beyond that, it provides the potential to analyse the aforementioned interdependence of technology and tactics, and to accept the challenge to develop new tactics vital in modern naval warfare.

The excellent practical experience made with the utilization of the Singer-ASTT and other simulators/procedures trainers in the German Navy initiated ideas about a "Simulation concept for the combat readiness training for the fleet" under effectiveness considerations with respect to costs, personnel and time such that the actual training at sea is cogently improved.

This concept will investigate the possibilities concerning the support of combat readiness training by simulators in the field of independent ship-squadron training in port and at sea and formulate appropriate requirements.

These ideas call for simulators concerning all future weapon systems; for existing weapon systems, it shows possibilities to create simulator capacities for the period 1980-1990. For special training aspects new simulators, at least a complement of existing simulators are required concerning

* surface warfare procedures,
* optical/optronic director system,
* ESM/ECM.

ABOUT THE AUTHORS

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LCDR BERND LEHMANN has been assigned to the Naval Tactical Training Group in Wilhelmshaven, Germany since 1977 serving as Commander for the technical-operational division. He is responsible for programming, maintenance and operation of the simulator to support the training and tactical development. Previous assignments include: Operation's officer on destroyers and commanding officer of FPBs. He holds the M.S. degree from the Naval Post Graduate School, Monterey in operations research.

SIMULATORS AND PARTS CONTROL

DONALD K. SWANSON
Defense Electronics Supply Center

INTRODUCTION

Parts control is a term used for several years in the military departments to describe an effort to control the use of nonstandard parts in newly designed equipment and weapon systems. Today it is much more than this. It is a concentrated effort by the military equipment and systems acquisition offices, utilizing Military Parts Control Advisory Groups (MPCAGs) to not only maximize the quantity of standard parts used in all new design, but also to minimize the variety of part types used.

The benefits from this effort are:

a. Increased reliability and maintainability of equipment and systems.

b. Reduced costs to the government and the taxpayer of part documentation and qualification testing.

c. Fewer new part types entering the DoD logistic inventories and, therefore, reduced costs of maintaining those inventories.

This paper will attempt to discuss:

a. How the parts control program evolved through the use of MPCAGs.

b. The application of the program to the simulators developed by Naval Training Equipment Center (NTEC) and

c. Recent changes in the DoD Parts Control System.

EVOLVEMENT OF PARTS CONTROL PROGRAM

Today's expanded DoD Parts Control System has evolved over a period of more than 20 years. As far back as 1957 the Advisory Group on the Reliability of Electronic Equipment reported that electronic parts were a major factor in field failures of equipment and systems. A 1960 report by this group recommended that part specifications be updated to include measurable reliability requirements, thereby,making them more useable for design. Thus, the Established Reliability (ER) specifications were developed.

The recommendations of this report and the development of the ER specifications pointed out the fact that standardization must occur during the design phase if it is to improve equipment quality and reliability. Many other studies by committees and groups both in and out of government including a special DoD Task Group have arrived at the same conclusion. Therefore, it was to be expected in 1971 when the Assistant Secretary of Defense for Installations and Logistics directed that the military departments adopt the parts control program recommended by the DoD task group for the procurement of electronic equipment.

The Defense Electronics Supply Center (DESC) in Dayton Ohio, a supply center of the Defense Logistic Agency (DLA), and specifically DESC's Directorate of Engineering Standardization (DESC-E) was selected to provide engineering recommendations on part selection to the military procuring activities and their equipment contractors as a key part of the overall parts control effort. DESC-E was a natural selection as the first Military Parts Control Advisory Group (MPCAG) since fully 25% of all new national stock numbers (NSNs) being assigned each year were in the electronic parts federal supply classes (FSCs) being managed by DLA at DESC. This meant that a high-degree of parts proliferation existed in the electronic parts FSCs. Further, DESC-E already had a professional workforce to do the job. Electronic parts engineers and technicians in DESC-E had been preparing over 90% of the military specifications and standards for the military departments since 1962. In addition, DESC-E has also been acting as agent for the military departments in managing the qualification program and issuing Qualified Products Lists (QPLs) associated with the DESC prepared specifications.

By the time parts control was included in electronic equipment acquisition in 1971 two major parts control documents were in use - MIL-STD-891 (USAF) Contractor Parts Control and Standardization Program and MIL-STD-749 Preparation and Submission of Data for Approval of Nonstandard Parts. The Air Force had, through the use of MIL-STD-891 (USAF) and an agreement between DLA and Air Force, utilized the technical support of DESC in part selection on a number of new design contracts including the F-111 aircraft program. The Navy and Army usually applied variations of MIL-STD-749 or their own command oriented parts control methods and documentation to the acquisition of new

design equipment. Neither Navy or Army equipment procuring activities had used the services of DESC-E engineers in electronic parts selection prior to 1971.

PARTS CONTROL IN SIMULATORS AND TRAINING EQUIPMENT

In 1971 the Naval Training Equipment Center recognizing the problems to be incurred by the use of large quantities of nonstandard electronic parts, became the first Navy equipment acquisition office to enter an agreement with a DLA activity (DESC) to provide part selection support on new equipment contracts.

The agreement called for the DESC MPCAG to review all requests for approval of nonstandard parts which were to be submitted in accordance with MIL-STD-749. NTEC provided for DESC-MPCAG review of nonstandard parts on existing ongoing contracts as well as contracts yet to be awarded. Contract language was developed to provide for direct submission of nonstandard parts requests to DESC with a response required back to the contractor within 15 days. An appeal of the DESC recommendation could be made to NTEC by the contractor if he did not agree with the DESC recommendation. In the absence of an appeal, the DESC recommendation was considered an NTEC decision. Figure 1 shows the work flow used by NTEC and DESC since 1972. The agreement between NTEC and DESC is one of the strongest parts control agreements yet written because it includes the basics for a successful program. That is: (1) Timely, accurate, parts recommendations made by up-to-date parts specialists at DESC, and (2) A strong commitment to more reliable better quality equipment at reduced life cycle costs by NTEC program engineers.

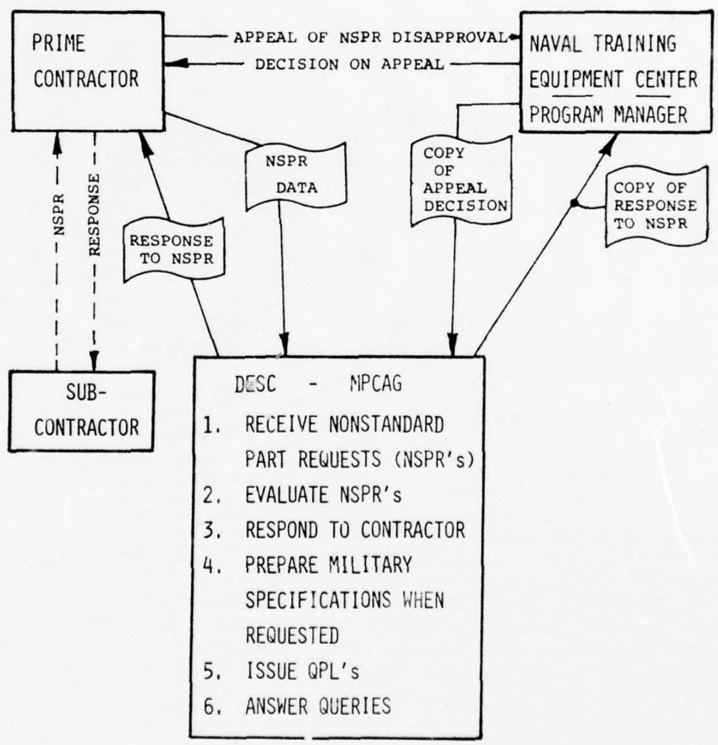

Figure 1. Parts Control Work Flow On Simulator And Training Equipment Contracts

If we examine the quantifiable benefits of a parts control program, we develop certain cost avoidances due to the elimination of the use of nonstandard parts. That is, we establish what equipment "could have cost" without a strong parts control effort.

These cost avoidances are based on acquisition as well as life cycle cost considerations as follows: (1) The replacement of a nonstandard electronic part type with a standard part eliminates the need for the government procuring activity to procure Original Equipment Manufacturer's (OEM) drawings from their contractors. These drawings can cost from $500 to $8,000 each depending on the electronic part type involved according to military procuring activities. (2) The replacement of nonstandard parts also eliminates the need, and subsequent cost to the government, for contractors to run lengthy and costly qualification tests on the nonstandard parts. (Since standard parts which are already qualified and listed on QPLs are recommended by the MPCAG.) These tests can run as high as $25,000 per test on some types of integrated circuits. (3) Life cycle cost impacts of the replacement of nonstandard parts include the prevention of new nonstandard parts from entering the DoD inventory and becoming stock numbered which can cost over $1,800 per nonstandard part based on a 10 year inventory life. (4) Each nonstandard part replacement also avoids maintenance costs of over $3,000 over an estimated 10-year life of the equipment according to military equipment managers. This is based on fewer failures of standard parts and thus less maintenance actions.

The DESC MPCAG has provided parts control support to NTEC on 63 contracts for simulators and training equipment since 1972. Thirty-three of these contracts are still active today. DESC engineers have evaluated a total of 6,119 nonstandard part types since 1972 and have recommended the replacement of 2,291 nonstandard parts with standard parts that perform the same function in the equipment. Applying the cost avoidance criteria discussed in the previous paragraph, we see the positive result of the NTEC parts control program in Table 1.

A review of the conservative figures in Table 1 shows that costs in excess of $21 million have been avoided by NTEC and DESC over the past six years and that for each dollar expended by the DESC MPCAG and NTEC contractors on the parts control program an expenditure of $53 was avoided.

A review of a current NTEC contract for the Infantry Remote Target System (IRETS) shows that replacing a relatively small quantity of nonstandard parts replacements can result in large cost avoidances for NTEC and the government (see Table 2).

This data indicates that more nonstandard microcircuits were replaced than all other part types combined. Further, because of their complexity, the cost of OEM drawings and qualification testing of nonstandard microcircuits made the value of standard microcircuits (column 4) much greater than other types of devices. The IRETS is an ongoing contract and additional cost avoidances are expected. It serves well here to testify to the continuing success of the NTEC/MPCAG parts control program for new design simulators and training equipment.

THE DoD PARTS CONTROL SYSTEM

Within the past two years, major steps have been taken by DoD to formalize the overall parts control effort not only on simulators but on all DoD systems and equipment development programs. One step was the issuance of DoD Instruction 4120.19 DoD Parts Control System on 16 December 1976. The significance of this instruction lies in the fact that it makes mandatory throughout DoD the use of a parts control program in the development of major systems and equipments. The instruction further assigns responsibility for its implementation through the use of DLA established MPCAGs with the Military Departments retaining final authority on part selection for their new design equipment.

Meantime DLA has also taken steps to expand the program by establishing a second MPCAG function in 1975 at Defense Industrial Supply Center (DISC) in Philadelphia to assist in the control of mechanical part types such as fasteners and bearings which are the second fastest growing part categories in the DoD inventory. Recently, two other DLA centers, Defense Construction Supply Center (DCSC) and Defense General Supply Center (DGSC), were directed to establish MPCAG functions to provide parts control support when requested on the part categories managed by those centers.

TABLE 1. IMPACT OF NTEC/DESC PARTS CONTROL SINCE 1972

- NONSTANDARD PART TYPES REPLACED		$2,291
- DRAWINGS AVOIDED (2291 ÷ 2) 1/		1,146
- PRODUCT TESTS PREVENTED (2291 ÷ 4) 2/		573
- ITEMS KEPT OUT OF INVENTORY (1146 X 3) 3/		3,437
- ESTIMATED MAINTENANCE ACTIONS AVOIDED/YR		2,291
- LIFE CYCLE COST AVOIDANCE		
1. ACQUISITION PHASE DESIGN TO COST (DRAWINGS/TESTS PREVENTED) (BASED on FY77 ESTIMATED SAVINGS PER PART TYPE)	$ 8,495,000	
2. OPERATIONS & SUPPORT PHASE OVER EST. 10 YEAR LIFE OF EQUIP. (BASED on FY 77 EST. SAVINGS PER PART TYPE)	$13,230,000	
3. TOTAL COST AVOIDANCE (BASED ON FY77 EST. SAVINGS PER PART TYPE)	$21,725,000	

BENEFIT/COST RATIO

- NTEC COST	0
- MPCAG COST ($23.60 X 6,119)	$144,000
- ESTIMATED CONTRACTOR COST	$266,350
- TOTAL MPCAG AND CONTRACTOR COST	$410,350

- BENEFIT/COST RATIO (MPCAG ONLY) $\frac{\$21,725,000}{\$144,000} = 151:1$

- BENEFIT/COST RATIO (MPCAG & CONTRACTOR) $\frac{\$21,725,000}{\$144,000 + 266,350} = 53:1$

NOTES:

1/ To be conservative, we assume that drawings are prevented in 50% of the nonstandard part replacements.

2/ We also assume testing is prevented 25% of the time to be conservative.

3/ Facts show that each drawing covers an average of three parts and each of these parts is assigned a separate NSN.

TABLE 2.

FSC	Description	Nonstandard Types Replaced	Value of 1/ Standard Part	Life Cycle Cost Avoidance
5905	Resistors	7	$7,470.50	$52,293.50
5910	Capacitors	2	7,470.50	14,941.00
5925	Circuit Breakers	1	4,743.00	4,743.00
5930	Switches	4	7,993.00	31,972.00
5935	Connectors	6	7,868.00	47,208.00
5940	Terminals, Lugs	9	4,743.00	42,687.00
5961	Semiconductors	10	8,872.00	88,720.00
5962	Microcircuits	124	12,932.00	1,603,568.00
5970	Insulators	1	4,743.00	4,743.00
6145	Wire & Cable	7	7,868.00	55,076.00
Misc.		1	2,555.50	2,555.50
		172		$1,948,507.00

1/ The value of a standard in each part category or FSC has been calculated using the DoD accepted cost-benefit analysis techniques for parts control developed by DESC. Further information on this subject may be obtained from Mr. Charles Gastineau, DESC-ES, Telephone 513-296-5086 or Autovon 850-5086.

The next step by DoD was taken in April 1977 with the publication of MIL-STD-965 Parts Control Program. This standard, for the first time established coordinated DoD procedures and requirements for implementing the parts control program. MIL-STD-965 also identifies the Federal Supply Classes (FSCs) for which parts control support is to be provided. The new standard supersedes MIL-STD-891 (USAF) and MIL-STD-749 among other documents and should be referenced in future contracts according to the following criteria:

a. All major weapons systems.

b. End items of equipment where provisioning and follow-on logistic support is required.

c. Any other contract or internal government program where life cycle cost benefits through parts control can be derived.

The requirements of MIL-STD-965 are tailorable to the needs of the individual development program. It includes two basic parts control procedures. Procedure I includes the requirement for the development of a Program Parts Selection List (PPSL) tailored to the needs of each contract. The PPSL is to contain a list of part types from which designers may choose discrete parts for use in their design. Only those parts listed on the PPSL may be used in the design and all part types to be added to the PPSL must be submitted to the MPCAG for evaluation prior to listing. Procedure I is intended for use on most development contracts where only one prime contractor and few if any subcontractors are involved. Procedure II requires a PPSL but also includes the establishment of a Parts Control Board (PCB) to be chaired by a representative of the prime contractor. It is intended for major development efforts when numerous subcontractors may be involved. The PCB membership typically includes major subcontractors and representatives from the military program office at least one MPCAG representative. The MPCAG representative is usually one from the MPCAG having predominate interest in the parts used in the equipment. A PCB may meet on a monthly basis during the early phases of design and less often thereafter. These PCB meetings provide for discussion of parts proposed for addition to the PPSL as well as an interchange on critical part applications and long lead time impacts.

Another important cost-effective feature of MIL-STD-965 is that it provides for telephonic requests for the addition of parts to the PPSL. The contractor's designer is urged to call the cognizant parts specialist within the DLA-MPCAG and discuss part selection problems. The MPCAG engineer will document the request and provide a verbal recommendation within two working days if not immediately. Follow-up paper work to document the recommendation is then forwarded by the MPCAG to the contractor and the military procuring activity. This obviously saves on contractor generated paperwork and results in a cost avoidance for the government. Figure 2 shows the services and type of support typically provided by DLA MPCAGs under MIL-STD-965.

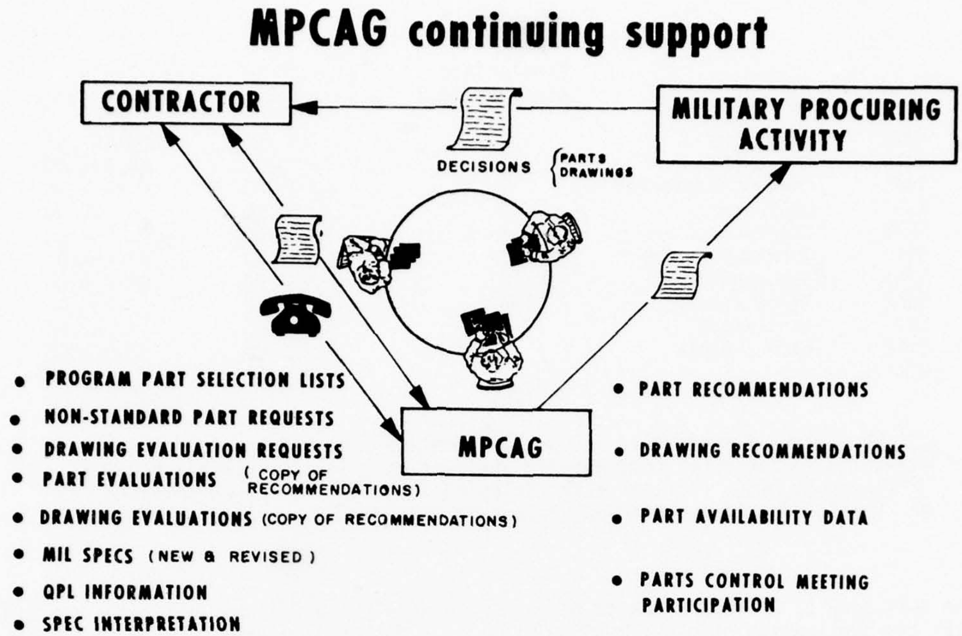

Figure 2. Operation Of Military Parts Control Advisory Group (MPCAG) In Design Selection

THE FUTURE LOOKS GOOD

The DoD Parts Control Program has come a long way since its beginning in the late 1960's and early 1970's. One of the reasons for its success lies in the foresight and positive attitude of NTEC engineers who came to grips with the problem of controlling non-standard parts in their equipment early in the program and developed solutions through the use of DESC's MPCAG.

The total program has continued to grow as has that portion of concern to NTEC and simulator contractors. Table 3 shows the growth of the program at DESC through fiscal year 1977.

TABLE 3. GROWTH OF PARTS CONTROL PROGRAM

Fiscal Year	Total Contracts Supported	Life Cycle Cost Avoidance $ Millions	MPCAG Cost $ Millions	Benefit/Cost
1973	57	$40	$ .67	58:1
1974	97	53	.77	68:1
1975	142	84	.83	101:1
1976	184	114	.84	136:1
197T +1977	290	127	1.35	94:1

It is expected that during FY 1978 the DLA-MPCAGs will provide parts control support to over 330 contracts, and by 1980 from 350 to 400 contracts are expected to require parts control support from the MPCAGs. The Parts Control System is recognized as an extremely cost-effective program at all levels within DoD. It is a program that results not only in life cycle cost avoidances in equipment acquisition and usage but also contributes to greater reliability in systems for the military services.

ABOUT THE AUTHOR

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PAPERS PUBLISHED BUT NOT PRESENTED

A COMPARISON OF COMPUTER-AIDED TRAINING VERSUS CONVENTIONAL METHODS

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The capability of the digital computer has been examined by training equipment designers for several years with the hope of improving the speed and/or quality of instruction. The general term, computer-aided instruction (CAI), has emerged to describe the use of a computer to prompt, provide feedback, adjust task difficulty, or enable flexible sequencing for learners and/or training facilities. The use of a computer in these roles is generally assumed to improve instruction, and possibly reduce recurring costs by lowering instructional personnel requirements. However, research comparing traditional instruction with CAI is somewhat limited in terms of generalization making verification of this assumption for a particular training situation difficult. The study reported here is intended to extend understanding of the use of CAI to the depth control task of a remotely controlled submersible vehicle (RCSV).

Of the many potential computer applications to the problem of learning to control depth of a RCSV, two were selected. First, an adaptive algorithm was constructed to adjust the level of difficulty that an operator experienced while learning the control task. Second, the level of disturbance was shown numerically to the operator, thereby providing feedback about his performance. Thus, the computer was used to vary the task difficulty in accordance with an operator's performance and provide feedback to the operator about his performance.

Two approaches to varying task difficulty were considered at the outset of this study although only one was tested. The first approach considered would have operated on the vehicle or control system dynamics to lower the difficulty of control for beginners. An algorithm modifying the task difficulty by this technique would be based on a response variable, and should be distinguished from stimulus variable modifications. In contrast, this latter technique adjusts task difficulty by varying a disturbing force.

A vehicle such as a RCSV is designed to be stable unless disturbed by a force; some disturbing forces arise from an operator's control commands while others result from changes in water temperature, salinity, or current. Experienced control operators minimize the amount of self-induced disturbance but beginners often inject a good deal of disturbance which, when mixed with environmental disturbance, is experienced as an overwhelming control task. The use of an adaptive model to add or subtract environmental disturbance in accordance with an operator's performance may aid beginners in distinguishing their own disturbance from that of environmental sources and, therefore, enable them to learn more clearly the effects of their control commands. This approach to an adaptive model was selected for the study reported here.

In brief, this study examined the effects of CAI on a beginner's performance in learning to control RCSV depth. Two groups of subjects were involved; one group attempted to learn the control task with the CAI model while the other group had the same amount of practice but under constantly difficult conditions. The performance of the groups was compared for training and transfer trials in order to assess the merit of CAI as applied to this particular task.

METHOD

Subjects

From a pool consisting of clerical and engineering personnel, 18 volunteer test subjects were selected on the basis of availability during the data collection period; the group was composed of three females and 15 males.

Some of the test subjects were experienced in the control of aircraft and/or ships; this experience varied considerably from one hour in a simulator to several years as senior operational personnel. Fifteen of the subjects had no prior experience directly related to the experimental task.

Experimental Setting

A modular, reconfigurable control station was used as the operator's station. This station, shown in Figure 1, presented stern plane position, depth rate, ship's angle, depth error, speed, depth, and problem difficulty level to the subject (other displays were present but inactive during the experiment as they did not pertain to the task of depth control). The subject controlled the stern planes with a hand lever that when pushed forward caused the planes to go into a dive position and when pulled back caused the planes to rise.

The control station was interfaced with a digital computer which was programmed with the equations of motion for the simulated vehicle. This computer also contained the adaptive algorithm, data recording software, disturbance model, and additional programs needed for the real-time simulation. A test conductor's station, shown in Figure 2, was used to control the simulation and data recording. The controlled vehicle was a miniature, remotely controlled submersible approximately 30-feet long with only stern planes for pitch/depth control.

Adaptive Algorithm and Disturbance Model

Ten levels of difficulty were selectable by the adaptive algorithm or the test conductor. A subject using the CAI condition experienced an increase in difficulty every 90 seconds providing depth error did not exceed 10 feet at any time during the 90 seconds. If a depth excursion larger than 10 feet occurred, the difficulty was decreased one level; if control was regained and maintained for 30 seconds, the difficulty was increased to the prior level. Successive depth excursions greater than 10 feet resulted in one level decrements until the subject was back to the starting level.

The disturbance model was constructed from six sine waves of different frequencies. The frequencies were selected so that they would not be higher than the response of the RCSV nor lower than would permit one complete cycle within the training trial-time period. The sum of these sine waves was multiplied by a gain and the level of difficulty (1-10). The disturbance force was applied through the center-of-gravity of the RCSV causing a vertical acceleration which appeared to the operator as a disturbance to the depth of the vehicle.

Experimental Design, Procedure, and Performance Measures

A split-plot design was used for this study. This is a factorial design with block-treatment confounding; in the study described herein, the between-block or nonrepeated measures variable was the training technique (CAI vs Fixed difficulty) while the within block or repeated measures variable was the transfer task (three difficulty levels: low, medium, high; and a depth changing maneuver). The complexities and limitations of this design were warranted by the availability of subjects and the nature of the experimental treatments; moreover, tests for homogeneity of pooled variances indicated the acceptability of this technique.

As indicated by the above design, two basic subject groups were obtained by random sampling from the volunteer pool. One group, designated the CAI group, began each training trial with a difficulty level of 1 and progressed as determined by the adaptive model up to a level of 5. Progress within each training trial was determined by the subject's performance; it was possible for a subject to spend most of the trial at level 1, level 5, or any level or combination of levels in between. The other group, designated the Fixed group, began each training trial at a difficulty level of 5; this difficulty level was not varied during any of the training trials.

Each group had three 10-minute training trials separated by approximately 1 minute of rest. At the end of the three training trials, both groups were given a series of four transfer trials. The first three of these trials required the subject to maintain a depth; each of these three had a different difficulty level associated with it (low=1, medium=5, high=10). The fourth transfer trial required the subjects to execute a 100-foot depth change. At the conclusion of the fourth transfer trial, the subject had completed the experiment.

All subjects received a welcoming and explanatory letter outlining the basic goals of the study; when a subject arrived at the simulation facility, he/she was taken to the test station and read the following instructions:

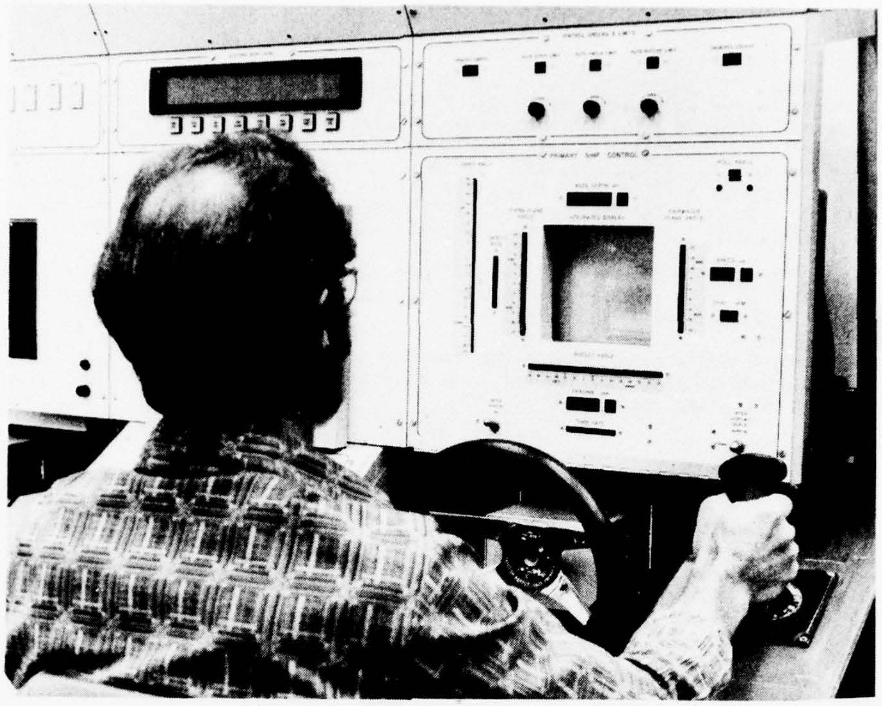

Figure 1. Operator's Control Station

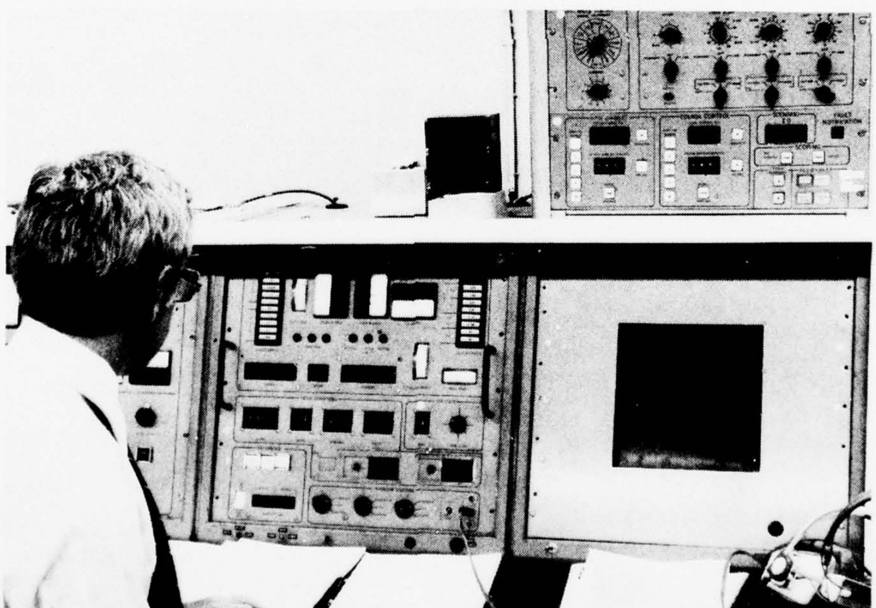

Figure 2. Test Conductor's Station

WELCOME:

You have been asked to participate in a study intended to investigate the utility of various submersible control training techniques. The task you will be trying to learn involves remotely controlling the sternplanes of the submersible vehicle to maintain or change depth. The planes are controlled by this (point) control lever; pulling back on the lever causes the planes to go up as shown by this indicator (point). When the planes go up, the front of the submersible will go up as shown here (point) and depth will decrease as indicated by the depth gage (point). The reverse of all this happens when the control lever is pushed forward. In short, pull the lever back to go up, push the lever forward to go down.

In addition to the indicators that I have already shown, the CRT directly in front of you shows depth error; when the cross is within the box, depth error is within an acceptable limit. Your task will be to keep depth at 300 feet.

Although ship's course can be controlled from this station, it does not pertain to the present investigation and should be ignored. Let me briefly describe the remaining indicators in front of you. (Point and explain.)

Do you have questions?

It is time for you to try controlling the submersible. To get started, push these buttons when I indicate (depth and course entry). We will need to talk over this head set as I will be up there (point). Let's get started.

If a subject had exceptional difficulty becoming oriented to the task, a modest effort was made to get him/her started; this was done for both groups and never exceeded a few orienting comments within a 2-3 minute period. With the exception of these efforts, all subjects were on their own to learn the task of depth control.

Performance measures consisted of RCSV responses, operator control commands, and the task difficulty level as determined by the adaptive model (pertains only to CAI group during the training trials). A listing of all performance measures is given in Table 1.

TABLE 1. PERFORMANCE MEASURES

1. RMS depth error
2. Integrated absolute depth error
3. Proportion of time within $\pm$1-foot depth band
4. Frequency of sign reversals in hand controller position
5. Performance index (mean quadratic combination of depth error and plane position)
6. Mean absolute plane rate
7. Percent time planes saturated (displaced to maximum position)
8. Mean absolute hand controller displacement.

Training Trials

Both CAI and FIXED groups were given three successive 10-minute training trials. Recalling that task difficulty for the CAI group was determined by ability to control the RCSV depth, it would be expected that the average task difficulty would increase as training progressed. Figure 3 shows that this did occur; however, it is interesting to note that after 30 minutes of training the average difficulty level had reached only 3.8; the FIXED group experienced a constant difficulty level of 5 throughout the training trials.

It is difficult to directly compare the performance of the separate groups during training because they were not working at the same level of difficulty. The question of whether the FIXED group was learning can be answered only indirectly by examining the change in selected performance measures as shown in Table 2. These data generally reflect modest performance improvements over the three training trials.

TABLE 2. SELECTED PERFORMANCE MEASURES FOR THE FIXED GROUP OVER THE THREE TRAINING TRIALS

	Trial 1		Trial 2		Trial 3	
	mean	SD	mean	SD	mean	SD
RMS depth error	16.05	10.05	12.80	16.90	9.90	6.00
Frequency of sign reversals in hand control position	.26	.11	.27	.13	.25	.15
Performance index	18.50	8.00	17.20	9.26	16.20	10.50
Average absolute plane rate	6.78	3.40	6.70	3.80	6.60	4.00
% time planes saturated	9.70	16.20	5.80	13.00	8.00	13.00

Transfer Trials

Three transfer trials followed the training trials for both groups; to the extent that operators had learned to control the depth of the RCSV during the training trials, performance on the transfer trials should have been improved. If the CAI method of instruction facilitated learning in comparison with the FIXED technique, it would be expected that CAI group performance would be better than that of the FIXED group.

The other main effect examined in this study was the level of difficulty of the transfer task. As it turned out, this variable accounted for more variance and had a more reliable effect than did the method of instruction: Analysis of Variance (ANOVA) summary tables for RMS depth error, proportion of time within a ± 1-foot depth band, the performance index, and average absolute hand controller deflection are shown in Figure 4.

Although the method of instruction did not turn out to be a statistically powerful variable, the general trend in much of the data indicated that the assumed benefits of CAI may have been realized. This is reflected by Figure 5 in which values of the above variables are plotted for the three transfer trial levels of difficulty. In the cases shown, the CAI group seems to maintain better RCSV control in that RMS error is lower for difficulty levels one and two, a greater proportion of time was spent in a ± 1-foot depth band, and the performance index is lower. This group also had slightly less average absolute hand controller deflection, a measure indicating that the task should have been less fatiguing. Two of the observed differences between the CAI and FIXED groups are significantly different ($P < .10$)*; in most cases the differences between the low and intermediate difficulty levels are significant ($P < .05$) for both groups.

The final transfer trial required operators of both groups to execute a 100-foot depth change maneuver. The purpose in doing this was to examine the transfer effects of both methods of instruction to a task not specifically encountered during training. The performance of both groups was essentially equivalent on this task. Average transition duration for the CAI group was 100 seconds while that of the FIXED group was 106 seconds.

DISCUSSION

CAI as a method of teaching remotely controlled submersible vehicle (RCSV) depth control was compared with a FIXED difficulty technique. The CAI group experienced three training trials during which their performance determined the level of task difficulty; the FIXED group had an equal amount of training but their experience was always at a constant (intermediate) difficulty. It was anticipated that the CAI group would learn depth control more rapidly because the amount of disturbance to the depth of the submarine was adjusted in accordance with their performance,

*In concluding that a reliable difference exists between the CAI and FIXED group, there is less than a .10 probability of being incorrect.

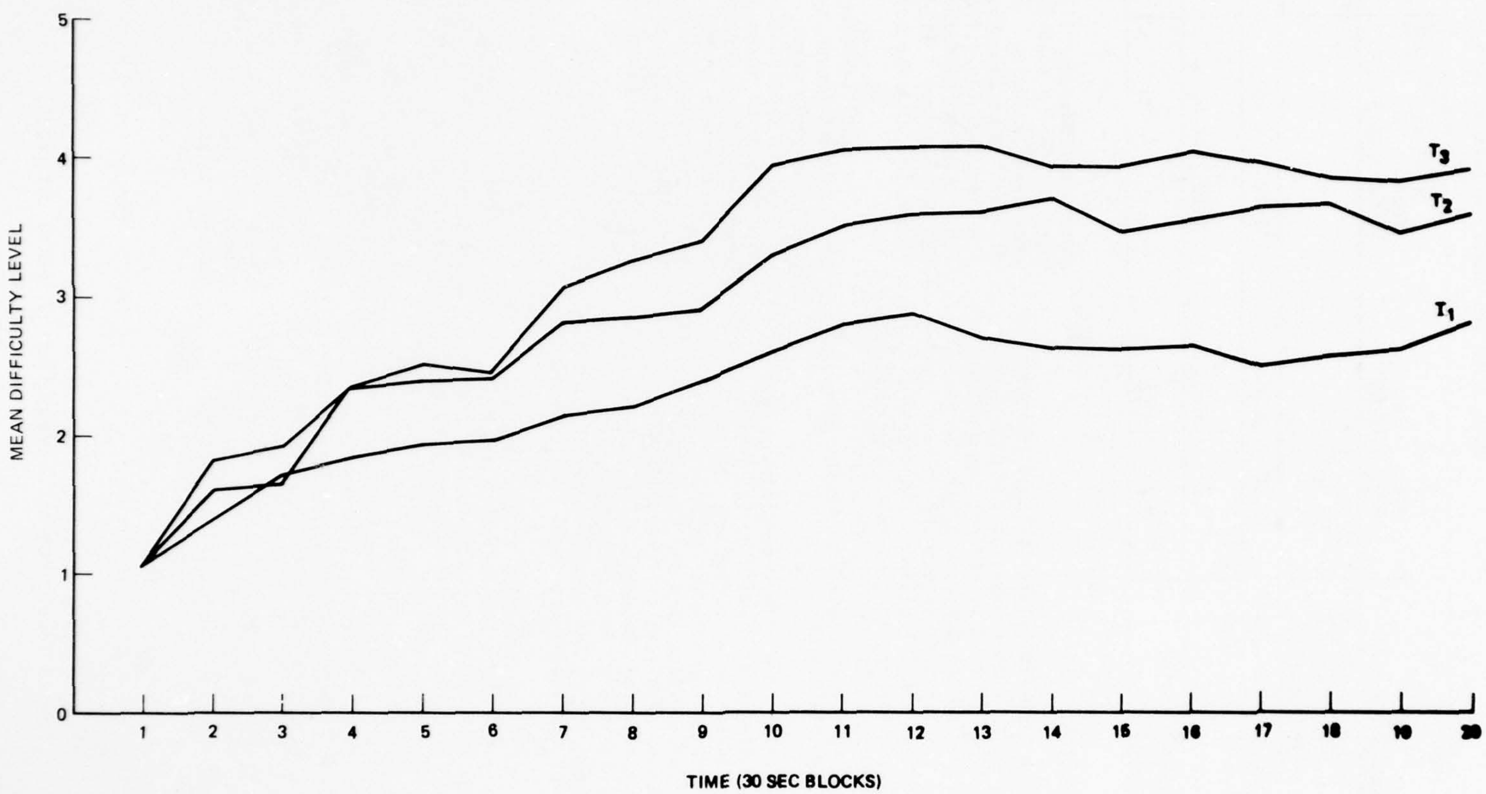

Figure 3. Mean Difficulty Level for CAI Group for the Three Training Trials

RMS DEPTH ERROR			
Source	df	MS	F
1. Between subjects			
a. A (type of training)	1	29.43	.3049
b. Sub w·group	16	96.50	
2. Within subjects			
a. B (transfer task difficulty)	2	230.82	6.71**
b. AB	2	56.10	1.63
c. B x sub w·group	32	34.38	

Proportion of time within ± 1 foot of depth			
Source	df	MS	F
1. Between subjects			
a. A (type of training)	1	.1116	3.455*
b. Sub w·group	16	.0323	
2. With subjects			
a. B (transfer task difficulty)	2	.428	36.87**
b. AB	2	.0553	4.77**
c. B x sub w·group	32	.0116	

Performance Index			
Source	df	MS	F
1. Between subjects			
a. A (type of training)	1	268.39	3.41*
b. Sub w·group	16	78.55	
2. Within subjects			
a. B (transfer task difficulty)	2	179.03	26.21**
b. AB	2	19.85	2.906
c. B x sub w·group	32	6.83	

Average Absolute Hand Controller Deflection			
Source	df	MS	F
1. Between subjects			
a. A (type of training)	1	53.78	1.33
b. Sub w·group	16	40.289	
2. Within subjects			
a. B (transfer task difficulty)	2	126.44	76.71**
b. AB	2	.08	.05
c. B x sub w·group	32	1.65	

* $P < .10$ ** $P < .05$

Figure 4. ANOVA Summary Tables for Four Variables

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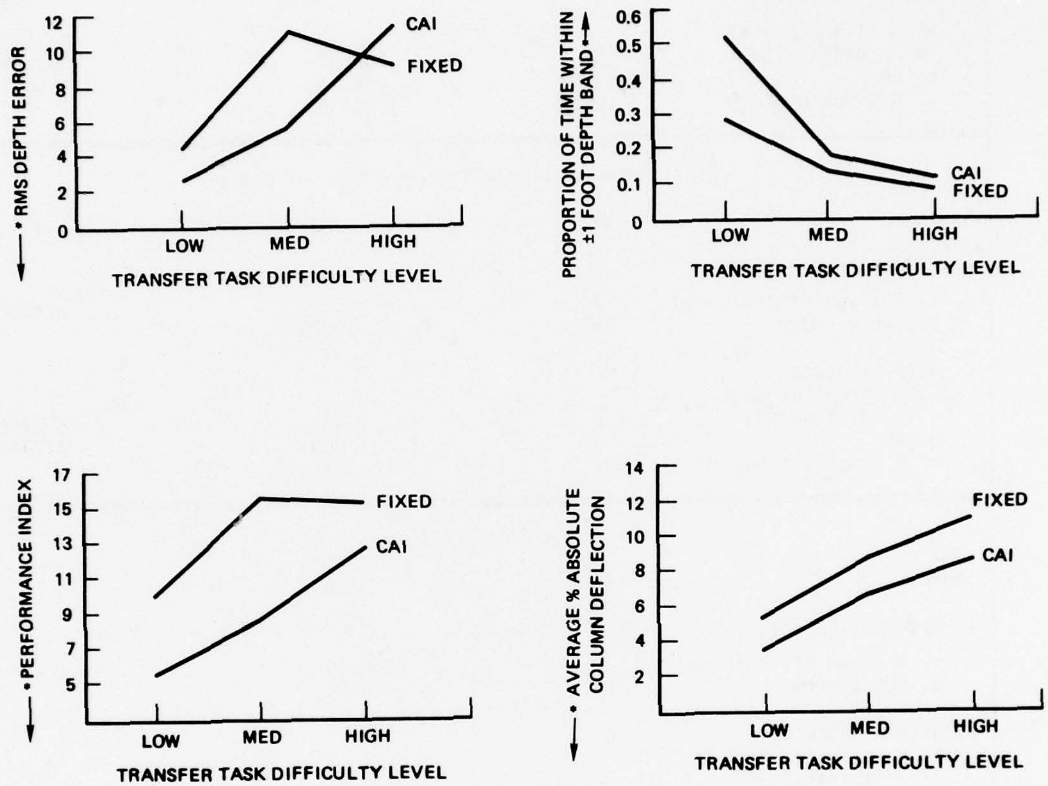

*Arrow indicates direction of performance improvement.

Figure 5. Mean Performance Measure Values for the CAI and FIXED Groups Across the Three Transfer Trials

thus permitting a clearer separation between the effects of their control commands (operator induced disturbance) and environmental disturbances. Although the trend in many of the performance measures was in support of this hypothesis, statistically reliable results were not obtained for all performance measures.

An examination of the performance of individuals within the CAI group revealed considerable variance. Some operators never progressed beyond difficulty level 1 during the thirty minutes of training while others advanced steadily. It seems reasonable that this wide variation in entering behavior is primarily responsible for the lack of statistically strong CAI effects.

Two aspects of the large ability differences obtained in this study appear to be of interest. First, an appropriate CAI system must either be designed with the level of entering ability in mind or it must be able to compensate for these differences. In the case of depth control, a CAI system would have needed to adjust response variables (i.e., RCSV dynamics) in order to lower the difficulty to an appropriate level for the operators participating in this study. Second, statistical reliability could most likely be obtained in a study like the one reported here by increasing the number of subjects; in effect, increasing the number of subjects tends to diminish the importance of the few operators who appear to be unable to establish control over the RCSV. However, this approach is not economically practical in an industrial research setting. Instead, experimental designs that permit a maximum of understanding with a minimum of subjects and time are dictated by the costs of test personnel and facilities.

CAI is most likely going to be an increasingly prominent part of modern instructional systems. Its success depends upon a thorough understanding of the many variables involved in a particular instructional setting, making generalizations difficult. In the case of RCSV depth control, this study has shown that the range of entering ability must either be constrained or the CAI system must be capable of a broader range of difficulty levels. More extensive training time may improve the picture of CAI presented in this study; but an approach that fails to reduce entry level complexity would not reduce the learner's intense frustration resulting from very limited performance improvements during the initial training periods.

ABOUT THE AUTHORS

DR. RONALD E. OFFENSTEIN is an Autonetics Marine Systems Division Consultant in Human Engineering and experimental design at Rockwell International. He is responsible for part-task and full-station real-time man-in-the-loop simulation studies. He also participated in the design of advanced control station concepts for various submarine and surface ship applications. At McDonnell-Douglas Astronautics, he was responsible for course preparation and presentation on propulsion and guidance systems, conducted simulated zero-gravity tests to verify operational procedures, and prepared task analyses for selected mission operations. In 1969, he joined Autonetics as a member of the Technical Staff, working on the F-111 Training Program, and experimental evaluation of plane and rudder quickened commands for SSN 688. He was Assistant Professor of Psychology at San Bernadino Valley College. Dr. Offenstein holds B.A. and M.A. degrees in psychology from California State College and a Ph.D. in psychology from Claremont Graduate School.

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SUPPORTABILITY DEMONSTRATION FOR FLIGHT SIMULATORS

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Supportability covers many areas in the flight simulator world, from reliability, availability, maintainability, to training, provisioning, logistics support, or technical data. Many of these areas are directly testable; many other areas can only be evaluated by indirect observation. Much effort has been expended in devising new methods of ascertaining whether flight simulators have met the needs of the Government. A major challenge in simulator acquisition today is specifying, designing, and enforcing support characteristics as design parameters. This paper explores a contractual method of obtaining a reliable and easily maintainable flight simulator for the life cycle of the device.

There are two objectives associated with supportability testing. The primary objective is to acquire a system with a high degree of correlation between the specified design parameters and the actual operational environment and requirements. Simulators may, in fact, be one of the few areas wherein such a high correlation can be achieved. The second objective is to provide for a coherent transition period from system design to a final organic support capability. Such a transition needs to have minimal perturbation on the normal support development process.

There are many alternatives to obtain integrated logistics support during the acquisition of a flight simulator. Interim Contractor Support (ICS) is frequently used to obtain the support necessary. This can, and many times does, simply delay many areas of support due to the division of responsibility between implementing and support commands. In the past, ICS has posed funding problems and acceptance by the support commands. Another approach could be to procure a flight simulator, test the device for specification requirements, run a reliability and maintainability demonstration, then transfer the device to the using command. This typical acquisition approach leaves the support command with little or no time to develop an organic capability to support the flight simulator frequently necessitating costly extraordinary actions. For flight simulators, there are six major activities that are occurring simultaneously - spares and support equipment delivery, operational test and evaluation of the simulator, technical publication preparation and verification, maintenance and operator technician training, depot-level repair center buildup, and follow-on provisioning actions. What is required is to tie these actions together with a logical orderly method, such that the acquisition process verifies each area before transition to the normal organic posture required by the Air Force.

The supportability demonstration approach will use the first production flight simulator as a test bed to evaluate support considerations. A 1-year demonstration and evaluation is performed on this device in an operational environment. Three support parameters are used to form the evaluation of the demonstration. These measurable and contractually enforceable parameters are: Mean Time Between Maintenance Actions (MTBMA), Maintenance Man-hours per Operating Hour (MM)/OH), and a form of operational availability. The MTBMA parameter measures unscheduled maintenance, whereas MMH/OH will cover both scheduled and unscheduled maintenance. Operational availability will be the fraction of scheduled missions that can be flown without a simulator failure or some variant of this. The combination of these three support parameters, while not all encompassing, is sufficient to successfully bind both support costs and training availability. The parameters are easily understandable goals for those personnel outside the acquisition arena.

The supportability verification, demonstration, and evaluation concept passes through three distinct, though not necessarily separate phases. The first phase includes the definition of the appropriate design parameters for the procurement solicitation. This definition and the design innovation it inspires will mold the reliability, maintainability, and availability into the flight simulator. Phase II includes those actions by the contractor and procuring agency up to the

actual on-site start of S demo. The in-plant actions shall include qualification testing using normal physical configuration audits, normal system acceptance test procedures, and a short-term high-risk reliability test. The short-term reliability test serves as an integrated and final checkout of hardware and software, assuring the procuring agency that the flight simulator has a reasonable chance of meeting the more rigorous requirements of the S demo. Phase III is the S demo phase.

After the simulator passes an initial checkout on-site, phase III begins. The contractor will use his own spares and approved support equipment. However, he may use Government Furnished Equipment (GFE) on an as-available basis, though not relieving him of this responsibility for providing necessary equipment. Qualification testing for all peculiar support equipment will be completed at the beginning of the S demo. A conditional acceptance by the Government marks the beginning of the 1-year S demo. The Government will continue the provisioning, depot-level repair center buildup, and those ancillary actions necessary to place ourselves in a full-support posture at the end of S demo. At the midway point in the S demo, the Government will conduct a technical publication verification of all contractor written manuals plus any supporting vendors' manuals that are deliverable under the simulator contract. The verification will be conducted by the trained personnel who completed the contractor school. The contractor will supplement the verification with technical writers and system engineers. After the verification, a final set of technical publications is presented to the Government and will reflect the actual as-built configuration. At the end of the S demo, the contractor's effort and documentation is evaluated by the procuring agency and, when acceptable, the contractor receives the liquidation of payments with appropriate adjustments. A final material inspection and receiving report is signed by the Government which does two things - one, it allows the contractor to receive payment for the S demo, and two, shows the Government that we received the flight simulator which has shown to be reliable and capable of meeting the Government's operational availability needs. It should be noted that this form should not be signed with unresolved deficiencies or engineering changes that affect the three support parameters.

To be effective, numerous details must be clearly discussed and included in the original competitive hardware solicitation. The 1-year supportability period is written in the contract in such a manner as to provide a sufficiently large incentive/penalty provision to ensure proper management and design attention. The contractor requirements spelled out in the contract include: providing all necessary spare and support equipment for the 1-year supportability demonstration (S demo), technical publications complete and validated prior to the start of S demo, technical schooling for the operators and maintenance personnel to include hands-on simulator experience, providing for total maintenance responsibility of the simulator including depot-level repair capabilities, delivering adequate documentation for evaluation of the three support parameters, and last, but most importantly, a clear requirement that if the support parameters are not met, the contractor will provide the necessary design changes and additional demonstration and evaluation time at no cost to the Government to clearly meet the support parameters. The requirements by the Government will include: facility and base support needs, simulator site observance of contractor activities, flying regularly scheduled operational missions just as if the Government owned and operated the flight simulator, a formal verification of the technical publications using contractor schooled maintenance personnel, and if deemed necessary, perform a maintainability demonstration at the end of the S demo (this could occur if the total number of maintenance actions did not provide a 90% confidence level estimate of MTBMA and MMH/OH).

There are direct and indirect advantages to the supportability verification, demonstration, and evaluation concept. Direct advantages include acquisition of a flight simulator whose basic support characteristics are defined, designed, and tested in accordance with actual field-level training conditions, hands-on training for operators and maintenance technicians, thereby increasing personnel stability, lead time for spares and support equipment eliminated, and support command in a firm organic support posture. Indirect advantages include Government evaluation of the integrated logistics support functions which are evaluated from a stable software and hardware baseline, controversies related to test verses field performance are eliminated since controlled field results are used, simulator consumption data has had a year to settle down and will provide better data to the support command's logistician, and finally, the using command has had a year of simulator use without the normal start-up of logistics delays that may adversely affect availability.

The supportability concept as presented here is a multifaceted method of integrating the

many activities that occur during the acquisition of a flight simulator. In reality, it also provides a transition period until the Government can obtain a full support posture. The basic guidelines for the supportability concept must be tailored for each simulator program, but the key factor must be that a set of contractually enforceable support parameters are specifying, designing, and forcing the simulator to meet the operational needs of the Government.

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A QUALITATIVE ANALYSIS METHOD FOR A MOTION SYSTEM OF COMBINED CONFIGURATION

DAVID YIH
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SUMMARY

Currently, the analysis method of a motion system is dependent upon the pilots' subjective evaluation. This paper describes a method using the data recorded by an instrumented dummy to qualitatively analyze a combined motion system. The function of the dummy is to record the time histories of linear (force) and angular (moment) accelerations imposed on the pilot's station during flight maneuvers. The dummy is a recording device instrumented with three linear accelerometers, three gyros, a seven-tape cassette recorder and two Polaroid instant movie cameras. The pilot's voice evaluation will use one of the tapes. The functions of the two cameras are to monitor and correlate the flight events.

INTRODUCTION

The simulator manufacturers and users customarily use the flight data to verify the math model of a flight simulator and determine the maximum displacement and time derivatives for designing a motion system. However, verifying a motion-simulated device, one is dependent upon the pilots' subjective evaluation. A motion-simulated device may be a motion system, g suit or g seat. Generally, there is a lack of validated data which indicate a device having met the design criteria. If there is no baseline (flight) data available, the analysis would be very difficult. How can we qualitatively analyze or at least interpret the pilots' subjective terms such as confused, distracted, irregular and unrealistic cues? Using the time histories of linear accelerations and Euler angular accelerations imposed on the pilot's station (eyeball or seat) during flight maneuvers, one may correlate the subjective terms with engineering expressions. The linear acceleration consists of three components (A_x, A_y, A_z) measured along the pilot's station coordinates in the directions of X, Y, and Z. The Euler angular acceleration consists of three components, roll ($\ddot{\phi}$), pitch ($\ddot{\theta}$), and yaw ($\ddot{\psi}$) accelerations measured between the pilot's station and inertia coordinates. The results will be very useful to the engineers for studying and improving a combined motion system.

This paper describes the qualitative analysis method and the use of a dummy instrumented with sensors, a recorder, and cameras to record the flight data and events in an aircraft and its simulator. The data recorded by the dummy in an aircraft is the baseline data. The qualitative evaluation of a simulated motion device is the analysis of the comparative results between the baseline and simulator data.

QUALITATIVE ANALYSIS METHOD

Based on our experience, the pilots complain against the low fidelity of a simulator whenever the performance data of the simulator deviate significantly from the flight data. Correcting the deficiencies, one has to modify the performance of the simulator to meet the flight data and refine it to meet the pilots' subjective evaluation. If the complaint is against the motion-simulated device, the correction is solely to meet the pilots' subjective evaluation. Furthermore, flight data is unavailable in a form which is suitable for the study and analysis of a motion-simulated device.

The qualitative analysis method is similar, in principle, to the one being used to verify the flight performance of a simulator. The differences include the collection and utilization of the flight data. The data of interest are the linear accelerations $(A_x, A_y, A_z)_p$ and angular accelerations $(\ddot{\phi}, \ddot{\theta}, \ddot{\psi})_p$ at the pilot's station. The vectorial summation of the linear accelerations will give us the information on the time history of the phase angle and the magnitude of the resultant vector (force). This is the most important data required for providing realistic motion cues. The proposed qualitative analysis method is quite different from the method currently used by the simulator industry in specifying and accepting a motion system. The current method does not include the use of time history of accelerations of flight maneuvers. However, the method does include the use of the performance tests in compliance with the specified tolerances on response frequency, maximum displacement and time derivatives. Obviously, the current method is inadequate to ascertain the fidelity of a motion system (reference 1).

Presently, no single motion-simulated device can provide the realistic cues covering high- and low-dynamic maneuvering and precision tracking. On the contrary, reference 1 cites a number of motion systems including those of special design which provide negative cues to

the pilots. A motion system can provide onset cue (jerk, change of acceleration) and very little sustained cue. On the other hand, the g suit and g seat can provide the sustained cue but not the onset cue. Undoubtedly, new simulators will incorporate a combined motion system. Hopefully, the analysis method will lead us to better understanding a combined motion system and to specify a system reasonably. Figure 1 shows the flow diagram of qualitative analysis method.

METHOD OF INTERPRETATION

The instrumented dummy is the device to record the time histories of the flight data in an aircraft or the simulator. The sets of data will consist of the acceleration data, correlated indicators' values, visual scene, and pilot's voice evaluation. Later, three sets of data will indirectly assist the qualitative evaluation. Figure 2 illustrates the time histories of onset, linear, and angular accelerations during a typical take-off maneuvering. Assuming the coupling effects equal to zero, the longitudinal (A_x) and normal (A_z) accelerations are only sustained values. For a combined motion system, the motion system, g suit and g seat must complement each other and function as an integrated system to provide realistic motion cues to a pilot. After washing out the onset acceleration provided by the motion system, the g suit or g seat must step in and function smoothly and continuously to provide the sustained acceleration cues.

Since all records of the flight data and events are synchronous, the pilot's voice evaluation will help us to locate the negative cues occurring in a certain time interval; the indicators' values will help us to detect the malfunction of the simulator; the visual scene will help us to analyse and correlate the motion cues. Examining the curves in Figure 2 has given us some clues to analyze and interpret the pilot's subjective terms often used in the evaluation. For example, complaint about unrealistic cue will probably occur in the time interval between t_0 and t_1 on the A_x curve. After washing out the onset acceleration, neither the motion system nor g suit could provide the realistic cues in that interval. The complaint about uncommanded and confused cues will probably occur in the time interval between t_1 and t_2 on the A_z or $\ddot{\theta}$ curve. The cause may be due to excessive time lag of the system or out-phase operation. The successful determination of the source of the negative cues is dependent upon the availability of the sets of baseline and simulator data recorded by the dummy. On the other hand, varying the time lag, magnitude of onset and sustained acceleration cues, phase angle, or gain of servo control system, one can easily extend the usefulness of the analysis method to study the pilot's perception of motion cues.

INSTRUMENTED DUMMY

Automotive and aerospace industries employ dummies for various experiments such as car crash tests and rocket assisted personnel ejection respectively. In the task, we will instrument the dummy with three linear accelerometers, three gyros and two Polaroid instant movie cameras (Figure 3). The accelerometers will sense the variation of longitudinal, lateral and vertical accelerations. The gyros incorporated with signal processors will provide the angular-acceleration signals. Avoiding the use of expensive telemetry system, a seven-tape cassette recorder installed in the dummy will record the time histories of accelerations imposed on the pilot's station and the pilot's voice evaluation. After completing a maneuver, the signals recorded on the tapes will drive a strip-chart recorder to obtain hard copies of the records. Driving a visual system, the pilot's station should be at the pilot's eyeball while driving a motion-simulated device, should be at the pilot's seat. To eliminate any errors due to the geometrical location, the dummy must sit on the pilot's seat as a human pilot. Therefore, a two-seat aircraft and simulator would be ideal to carry out the experiments. Figure 4 shows that the improper use of the station coordinates could lead to the computational errors particularly under high-dynamic maneuvering. The first camera located near the dummy's eyeball will record the actual scene from an aircraft or simulated visual scene from a simulator. The second camera located near the chest part of the dummy will monitor the indicators' values displayed on the instrument panel of an aircraft or a simulator. Synchronizing the operations of the sensors, gyros, recorder, and cameras is mandatory. Matching the data with the events, one should regularly mark the equal time interval on all tapes. Otherwise, there is no way to analyse the data.

CONCLUSION

The writer believes that in addition to the current method, the qualitative analysis method using the time history data of linear and angular accelerations at the pilot's station during flight maneuvers will definitely enhance the understanding of a combined motion system. One can use the results of the analysis to correlate the subjective terms with engineering expressions to develop a high fidelity combined motion system.

REFERENCE

"Simulator Comparative Evaluation," Tactical Air Cmd, USAF TAWC, Eglin AFB, FL, Nov 1977.

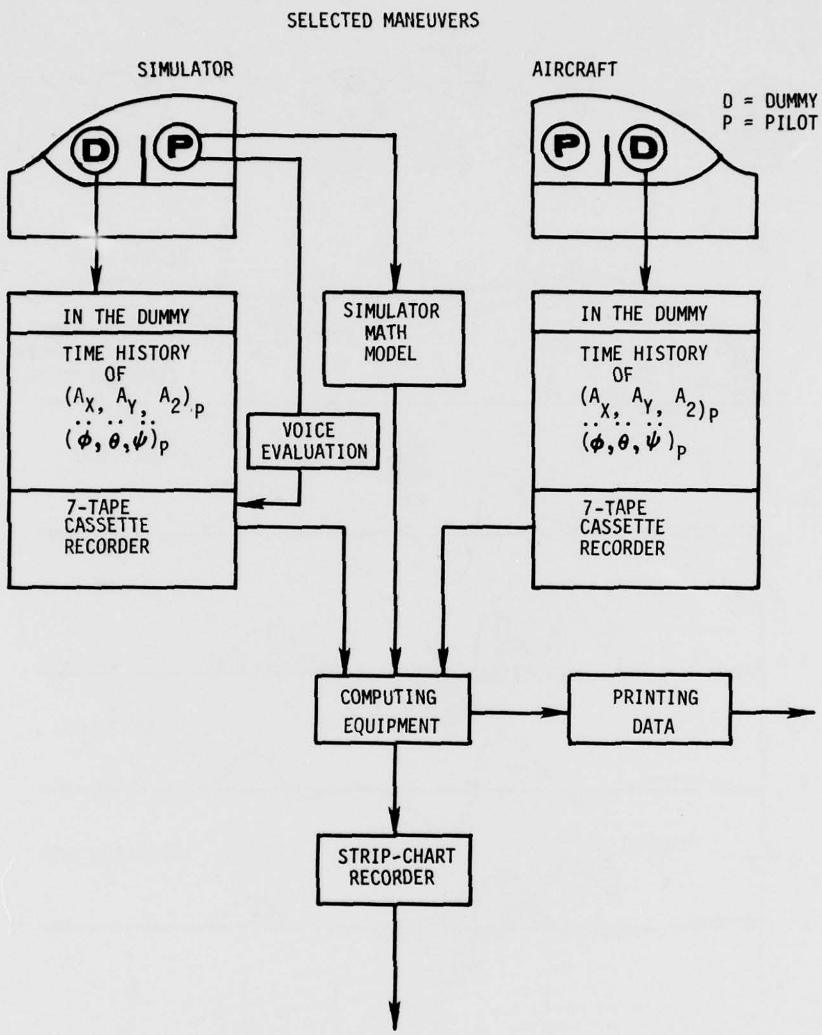


Figure 1. Analysis Flow Diagram

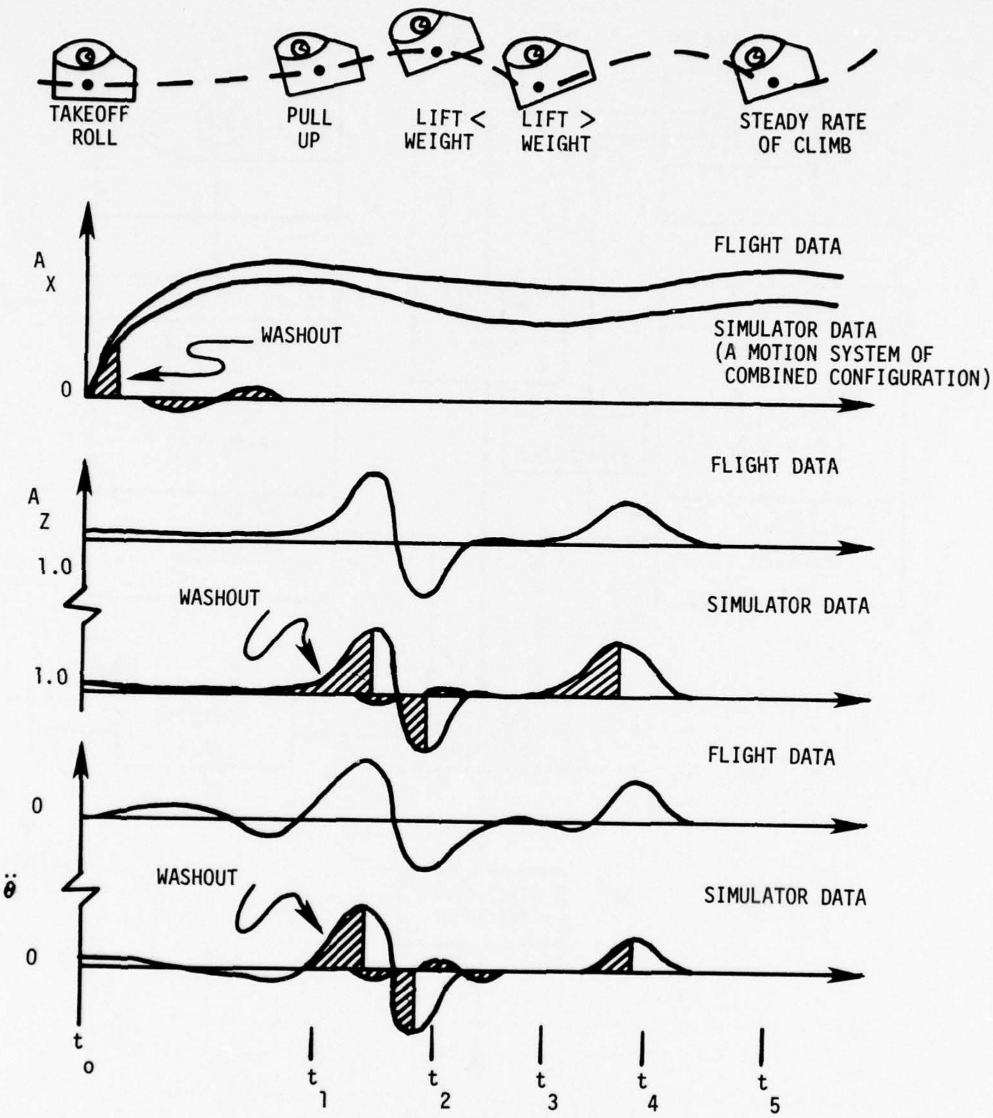
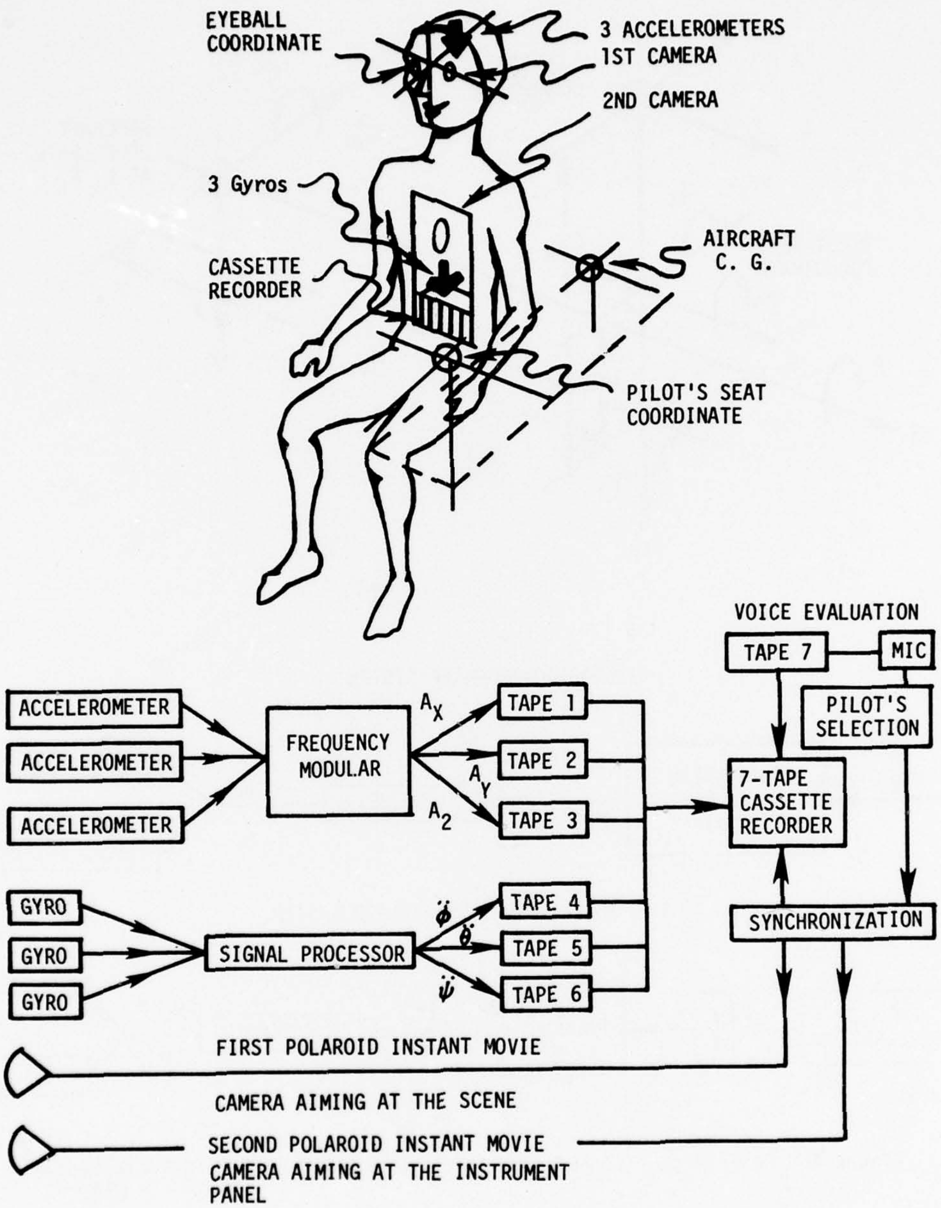
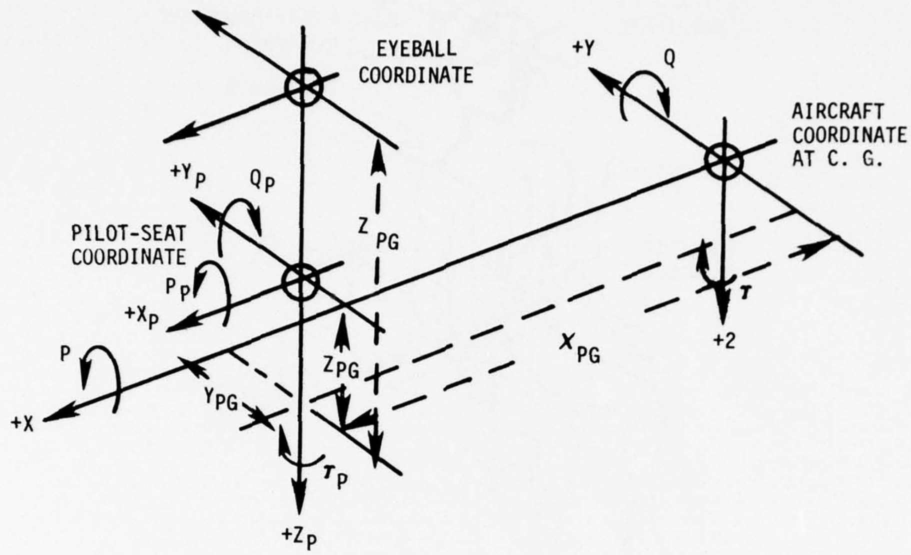


Figure 2. Takeoff Maneuver

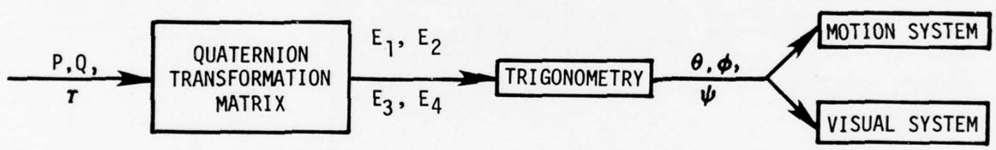


INSTRUMENTATION

Figure 3. Instrumented Dummy



AIRCRAFT COORDINATE SYSTEM



PILOT-SEAT/EYEBALL COORDINATE SYSTEM

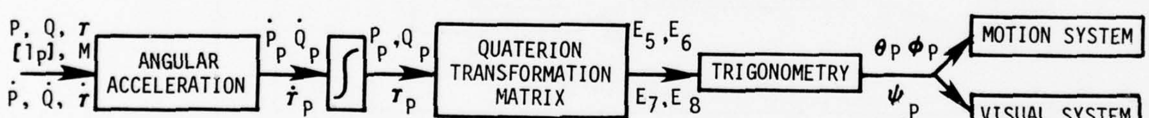


Figure 4. Euler Angles Computation Referred to Different Coordinate System

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SIMULATOR PROCUREMENT - SCIENCE OR SERENDIPITY?

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Science - Knowledge, often as opposed to intuition or belief. Systematized knowledge derived from observation, study and experimentation.

Serendipity - An apparent aptitude for making fortunate discoveries accidentally.

Science or serendipity? Versions of this question are too often asked of the simulator procurement process, especially following the unveiling of a multimillion dollar trainer which incorporates new and wondrous design features but fails to fulfill the end user training requirements. Following a brief look at some of the items which contribute to this criticism, we will discuss a comprehensive approach to instructional system management with emphasis on simulator procurement.

Several real world factors may contribute to any mismatch of simulator capabilities with training requirements:

- To ensure early availability, simulator design is often frozen while tactical equipment design and operating procedures are still evolving.
- Insufficient assets are devoted to front-end analysis during the conceptual stages of instructional program definition.
- Training requirements are inadequately defined or are not reflected in equipment specifications.
- Fleet and school inputs are requested or received too late to be incorporated into simulator design.
- The simulator is developed as a stand-alone entity rather than as a component of an integrated instructional system.
- Compromises are dictated by budgetary or political constraints.
- Alternative approaches to fulfilling training requirements are not identified or investigated.

Minimization of these factors and their effects is essential to the timely delivery of a simulator which fulfills the maximum percentage of valid training requirements within budgetary constraints.

There has been great progress in the past decade in developing procedures for defining that training which is required to ensure optimum readiness for both existing and emerging operational systems. The Instructional System Development (ISD) Program, improved Navy Training Plan (NTP) procedures, and the establishment of the Submarine Trainer Working Group (STWG) are but a sample of the myriad efforts which attempt to provide early definition of training requirements and the assets required to fulfill them.

The Training Information Management System (TIMS) illustrated in Figure I can maximize the effectiveness of such existing systems and procedures. As presently conceived, TIMS could be applied to an entire instructional system or any selected subset thereof, from tactical equipment conception through training system life cycle support.

The generalized TIMS encompasses all elements which could occur during the total life cycle of the most complex training system. As many as 50 or 60 top-level elements could exist. However, in actual use, only those elements which apply to a specific system and which are selected by each manager would be actuated. TIMS is not intended to replace existing procedures, but rather to provide an organized method by which various levels of management can determine and control all activities required during the acquisition and support of a total instructional system. Most of the elements shown in Figure I consist of activities which would be accomplished as a result of existing procedures. For example, many elements could be completed during the ISD process; TIMS would merely integrate them into the total effort.

TIMS is organized into four major functional subsystems:

- Training Equipment - Includes all the activities required to develop and acquire both hardware and software, from initial concept studies through life cycle configuration management and logistics support.
- Management and Control - Consists of management activities required to establish valid training requirements and provide program direction and monitoring. Includes testing. Highlights key events such as ready for training (RFT) dates.
- Personnel and Curricula - Encompasses activities which determine numbers and types of personnel required to operate and maintain operational and training equipment. Includes the development of curricula in support of specific learning objectives.

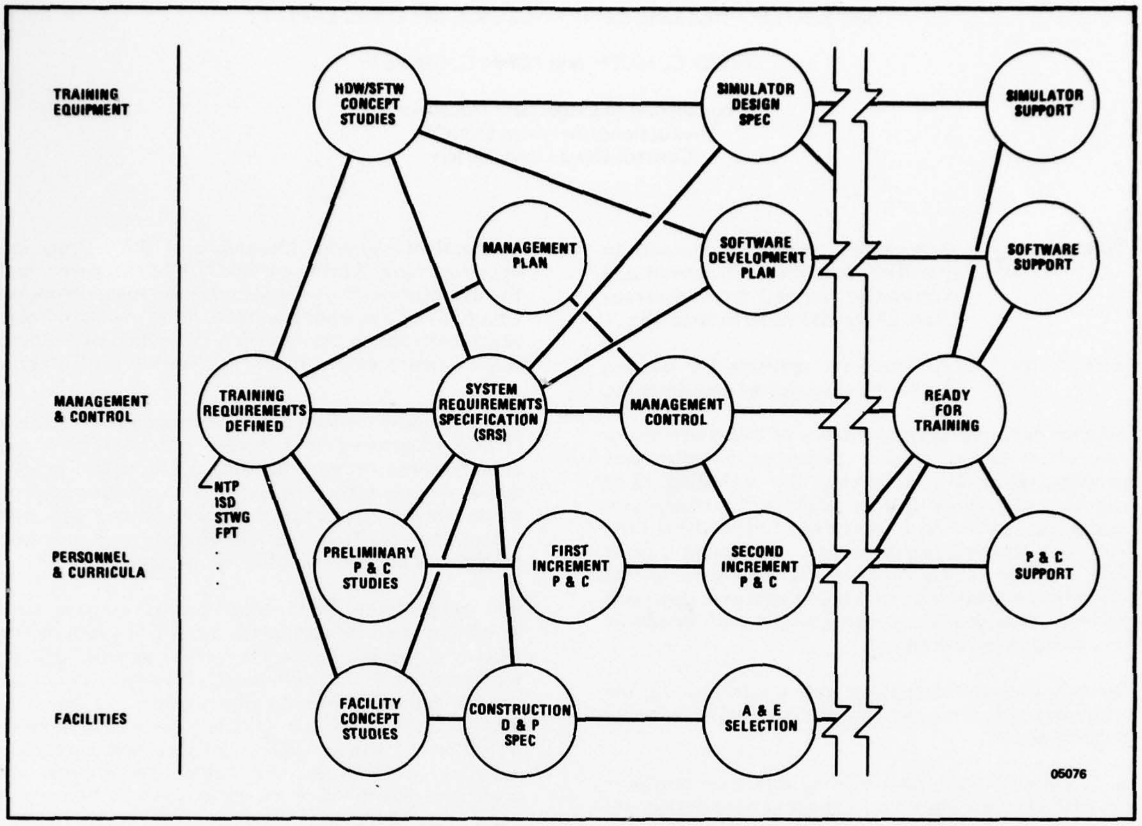

Figure 1. Training Information Management System (TIMS) Program

- Facilities - Includes all activities required to construct a new facility or modify an existing facility to house all or part of the instructional system.

The TIMS structured hierarchy is depicted in Figure 2. Both the top-level program chart and the lower level activity charts show the inputs, outputs, processes and interrelationships required at each level. The correspondence between levels is illustrated by lines C and C', which are actually the same, and which show the interrelationship between activities A and B. Individual activity charts identify all other activities from which an input is received or to which an output is provided.

This hierarchical structure provides to all levels of management easy to visualize displays of program activities at both the system and detailed levels.

We will now take a more detailed look at a subset of TIMS in which a particular training situation is analyzed. Looking back at Figure 1, we note that the entire system is based upon the early definition of training requirements. This requires inputs from all available sources, including Navy Training Plans, ISD, personnel studies, and Fleet Project Teams. These inputs are integrated and refined to definitize the total system requirements, which must remain visible and be considered throughout all stages of system development. The training requirements become a primary input to the System Requirements Specification (SRS) depicted in Figure 3.

During SRS development real world considerations are combined with the training requirements to define the most effective instructional system which can be achieved within existing constraints. Samples of the functions performed during the SRS development are described below:

- Inputs including the Navy Training Plan, ISD and Personnel Concept Studies are used to determine the numbers and kinds of personnel requiring training, and the type, level, length and location of courses to be provided.

- A determination of the types and quantities of training equipment which will best support the proposed curricula is made by consideration of such inputs as course information and tactical equipment and human factors studies. The

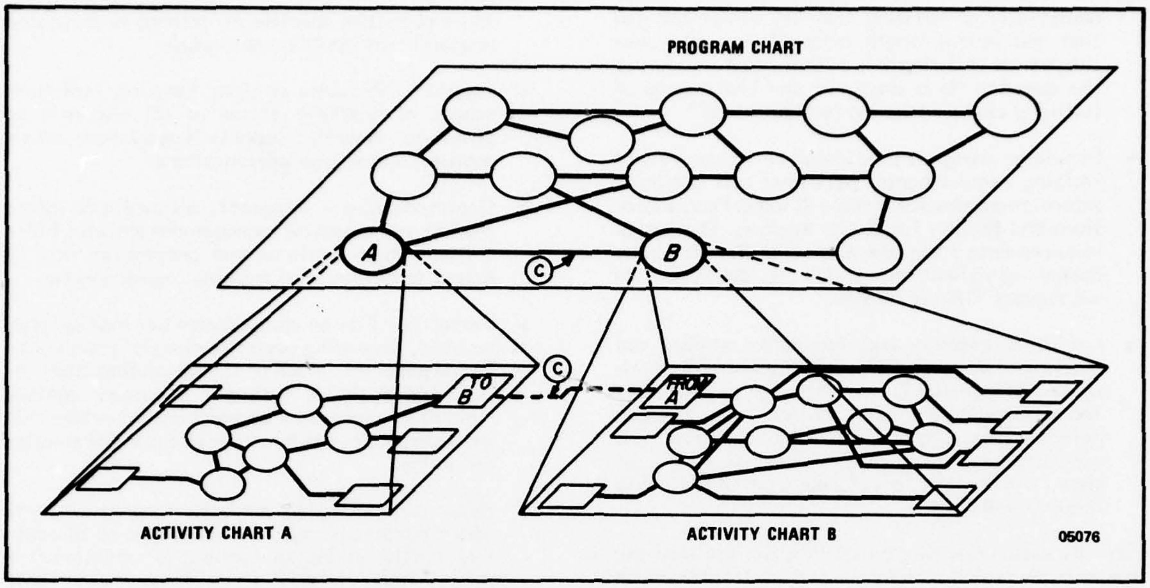

Figure 2. TIMS Hierarchical Chart Concept

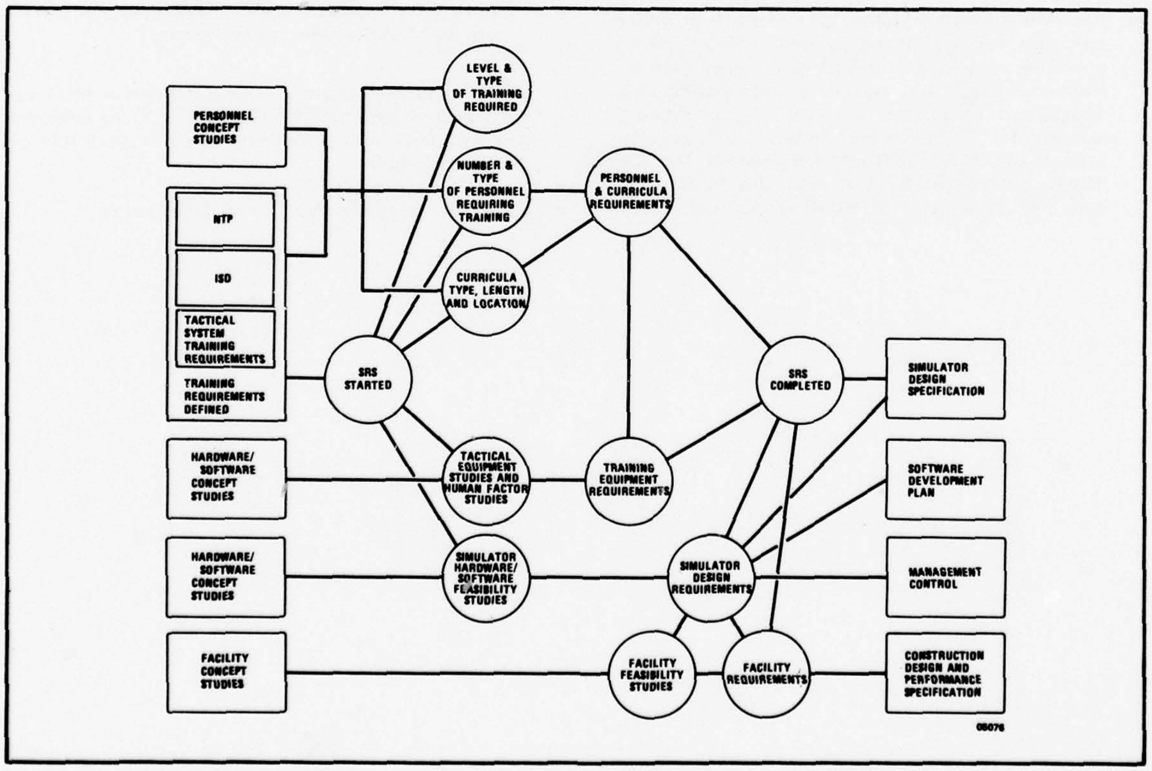

Figure 3. System Requirements Specification (SRS) Activity Chart

availability of existing training equipment and cost and course length tradeoffs are also considered. It is during this activity that we answer the question "Is a simulator the best means of fulfilling certain training requirements?"

- Simulator design is predicated on an analysis of training requirements, personnel and curricula information, simulator state of the art considerations and facility feasibility studies. The design requirements form the basis for the simulator design specification, which is developed in subsequent TIMS activities.

- Facilities concept and feasibility studies are performed in support of each phase of SRS development. Facilities constraints such as power and space availability and military construction policies may impact simulator design. The construction design and performance specification is ultimately developed from the facility requirements.

Our discussion has illustrated in a limited way the methods by which simulators can be treated as an integral subset of an overall instructional system. Other TIMS features which counteract the adverse factors previously discussed and which are critical to successful simulator procurement can be seen in Figure 4. TIMS is:

- Flexible - Easily expands or contracts to meet specific managerial objectives. Any system could be viewed as a subset of a larger system. For example, the system encompassing the weapons training of a new class ship could be a subset of a higher level system which encompasses the total instructional system for the class. In contrast, if a new simulator were required in support of existing curricula, only those activities specifically related to simulator procurement would be activated.

- Graphic - Provides straight forward, real-time means of tracking status of all elements of program. Readily supports Management Information Center type presentations.

- Comprehensive - Integrates all available information into a concise management picture. Fully utilizes those systems and procedures now in effect to define total training requirements.

- Versatile - Can be computerized or manipulated by hand, depending upon the size and complexity of the program. Much of the scheduling information and logistics data for a combat system simulator might best be mechanized, while this would probably not be cost-effective for smaller programs.

- Responsive - Rapidly analyzes program impacts and provides alternatives when real or theoretical modifications to manning or maintenance philosophies, schedules, budgets, home port assignments or other parameters are proposed.

- Cost-Effective - Provides early and realistic definition of projected budget requirements for the life cycle of the total system, with costs assigned to specific tasks. Allows early identification of subsequent budget impacts.

Early implementation of a comprehensive management system such as TIMS is essential to the achievement of maximum simulator effectiveness for the dollars available.

Science or serendipity? The choice is ours.

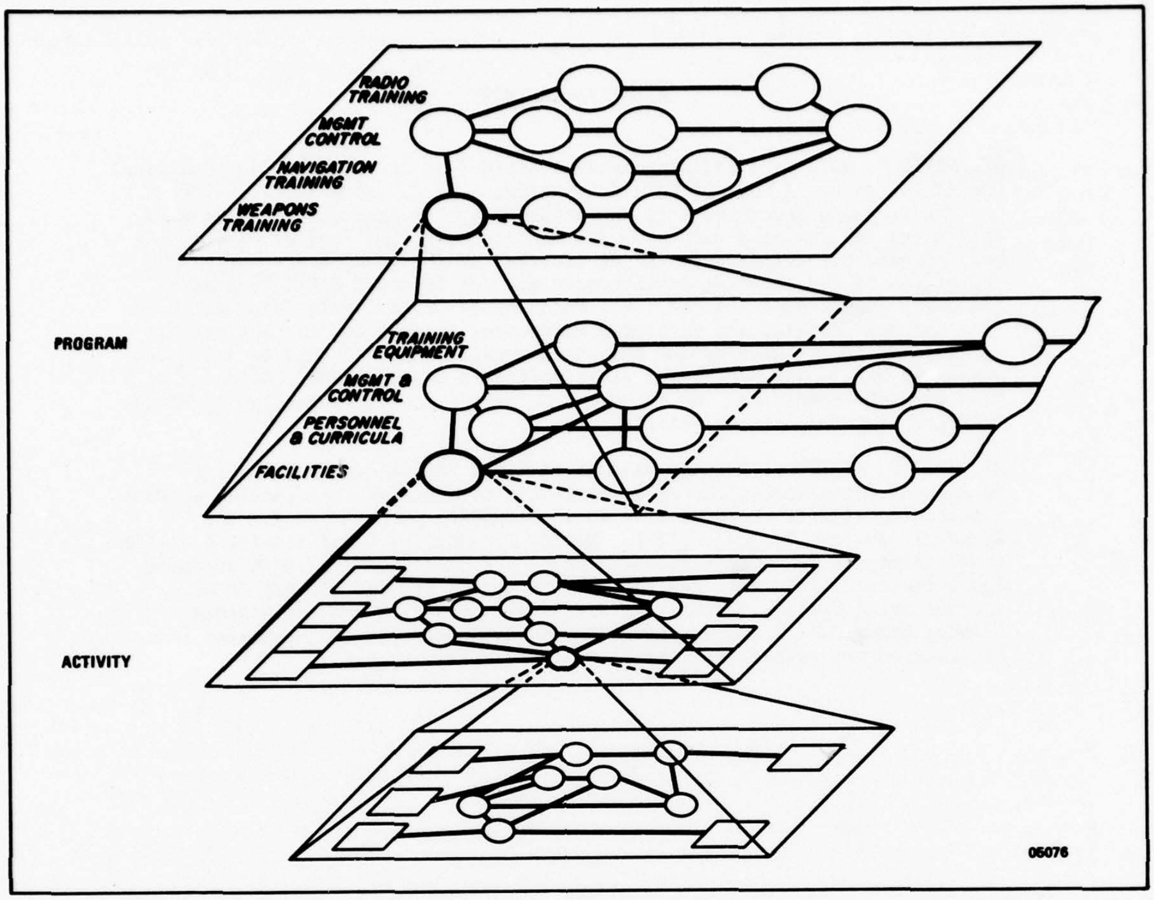

Figure 4. Expanded TIMS Hierarchy

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A LOW-COST SIMULATOR FOR AIR-TO-GROUND WEAPONS DELIVERY TRAINING

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SUMMARY

A feasibility model of a low-cost air-to-ground weapons delivery trainer using an area of interest presentation was assembled and tested at the Naval Training Equipment Center. The primary factor evaluated was the pilot acceptability of the visual cue presentation while performing the final phase of the ground attack mission. The preliminary pilot evaluation showed feasibility of the area of interest concept for providing visual cues during the final phase of the attack using rockets. Other attack modes should also be feasible. Compared to other approaches developed, the system cost of the NAVTRAEQUIPCEN system is less, and the risk is less to provide a deliverable trainer to the fleet.

INTRODUCTION

While the NAVTRAEQUIPCEN and the AF Aeronautical Systems Division have defined and studied designs of air-to-ground weapons delivery trainers since about 1950, the potential users of the proposed trainers did not actually state their requirements until recently, nor did the upper echelons of the DoD look at these trainers as a necessary item. Then the AF Tactical Air Command raised the question of an adequate visual display for the A-10 flight simulator to cover a number of missions including A/G attack. In December 1976, the Commander in Chief, US Pacific Fleet, in a letter to the Chief of Naval Operations and a letter by the CNO Deputy Director, Naval Education and Training, described the problem and requested solutions be developed as follows:[1] In recent years encroachment and ecological considerations have imposed evermore demanding constraints on target use (land area target complexes essential to the objective of achieving realistic combat training), impacting adversely on Navy and Marine Corps high-explosive ordnance delivery practice. Examples were given where complaints by the local citizenry of alleged property damage and excessive noise impact from bombing operations portend continued pressure to reduce or desist in the use of high-explosive ordnance on land-based target ranges. Yet, the requirement for conventional air-to-ground ordnance delivery training and ship-to-shore bombardment practice will continue for many years, until either electronic scoring techniques preclude the requirement or new weapons make current systems obsolete. He states a requirement for an inexpensive air-to-surface, unguided practice bomb that will be ecologically nondestructive and noise suppressed. CNO (DNET) added that other solutions should also be looked at.

The Director, Planning and Evaluation in the Office of the Assistant Secretary of Defense in early 1976 requested an independent assessment of the status of simulators and the role they should play in military tactical flight training. The assessment provided by Calspan was based on information obtained from a literature survey and survey interviews with individuals in industry and government who are knowledgeable about flight simulators, military tactical flight training and related matters.[2] One of the areas covered was ground attack.

The general purpose of Air Force Project Number 2235 was to analyze and demonstrate various technical approaches to air-to-ground weapons delivery simulation in order to reduce the performance and cost risk of procuring aircrew simulators which require A/G capability.[3]

An early device which had A/G capability, the AF Device F-151 Gunnery Trainer, was evaluated in 1957. Reference 4 reported that ground target slant range and dive angles were difficult judgments to make due to the narrow field of view (15°) and inadequate resolution (600 TV lines). Reduced or lack of fidelity required pilots to approach within 4-5,000 ft of the target to make a decision. The terrain area presented by the target projection system was inadequate for presenting motion perspective cues in peripheral vision. The evaluation pilots' estimation of slant range and dive angle was inadequate and consequently they crashed into the ground. During the first air-to-ground missions in the training demonstration, experienced pilots hit the ground in 39 out of 40 passes.

Finally, one more example of the need for a new approach is low cost. The NAVTRAEQUIPCEN received a requirement for an air-to-ground attack visual attachment for the A6E Weapons Systems Trainer, Device 2F114, and the A7E Weapons Systems Trainer, Device 2F111. The A6E WST Project Master Plan specifically required training in air-to-

ground weapon delivery (day mode only). The visual system requirement: FOV 270°H x 135° (90° up, 45° down), earth/sky projection in color, AOI 60° (diagonal). In both systems, the costs were greater than the user was willing to spend, without the knowledge of the exact FOV required. A typical cost example: for 100 miles of maneuvering, at 6500:1 scale, two 24' x 72' overlapping model boards would be required. The cost was estimated at $5M for the boards, $3M for the visual, and $2-3M for the R&D, or a total cost of $11 million.

DESCRIPTION OF THE FEASIBILITY MODEL

No new training or task analysis was conducted to establish the configuration of the simulator because the mission had been defined earlier.

Reference 5 defined the skills required for performance in the attack mission succinctly. Approach flight skills of navigation and/or observation while essential requirements for a complete mission should be well developed in separate, specialized, training tasks before beginning air-to-surface weapons delivery. Of course, general flying proficiency should be adequate. The training here must concentrate on the particular skills required for air-to-surface attacks. These skills include:

a. Attack preparation maneuvering to emerge on the weapons delivery flight path at a satisfactory range with good sight alignment

b. Tracking during the weapon delivery run

c. Timing of commence firing and cease firing or of bomb release

d. Use of sights and computer aides to attack accuracy

e. Integration of flying with weapons delivery.

Good judgment in the planning of attack preparation maneuvers and precision in their execution are essential to the successful air-to-surface attack. Premature emergence on the weapon delivery path exposes the aircraft to enemy fire during an unnecessarily long straight flight path. On the other hand, adequate time for sight alignment and tracking of target must be provided. The more precise the maneuvering, particularly the last roll-out onto the target track, the better the sight alignment and the less time required for aircraft control adjustment to come onto the firing track. Rapid and accurate adjustment of the aircraft to the target firing track and the development of fire control or bomb release timing are also essential. Firing at excessive ranges destroys accuracy and timing of bomb releases must be correct. Recovery initiation must be properly timed for continuation of firing after recovery initiation is wasteful of attack potential.

Since visual cues are an essential part of air-to-surface attack situations, visual displays, if they provide the necessary visual cues, should be useful in the development and training of skills to cope with such situations. Ideally, a training exercise should simulate for the trainee an actual combat situation with proper targets, full aircraft maneuverability and range, and enemy counteraction. He could then practice and develop his skills in all phases of the problem by flying air-to-surface attack missions in the world of the visual display. If this ideal situation could not be simulated, much useful training and practice could be obtained with a training device utilizing a visual display to reproduce standard training flight exercises used by Fleet Training Squadrons. By simulating these exercises, a visual display training device would provide training and practice with safety and economy and without delays occasioned by bad weather.

Reference 6 specifically states the visual simulation unsolved problems for the air-to-ground weapons delivery mission are: wide field of view as the minimum requirement and for full mission requirements, a wide field of view with medium resolution, in color.

Reference 2 provides a list of requirements for an A/G visual simulation system. Although general in nature, a visual display must provide:

a. Good fidelity of the mathematical models for the aircraft and scoring

b. Accurate aircraft data, force and motion cues

c. Improvements over present day systems in

Field of View
Resolution
Brightness
Gaming Area Size.

Using the above guidelines and existing resources in equipment, a minimum feasibility model as shown in Figure 1 was designed and assembled. A description and the performance

of the subsystems follows:

Image. This is a transparent two-dimensional ground scene, prepared as described in reference 6, backlighted by a light box, scaled 2500:1, full color and an artist's rework of an actual photograph, size 6' x 6', representing a 2.5 x 2.5 mile area. The fluorescent light box provides an average illumination to the probe of 410 FTL, with a range of 280-710 FTL. The wide range is dependent on the type of terrain viewed on the transparency.

Television Camera. Has a 1-inch 8507A Vidicon; Scan Rate 1023 lines/frame, 60 Hz, Video Bandwidth 32 MHz, Automatic Light Range 0.1 - 5000 fc, and geometric distortion less than 2 percent. Resolves all ten shades of gray on EIA TV Resolution Chart, with 0.5 foot-candle highlight illumination on the face of the camera tube. Resolution is 1100 TV lines horizontally and 700 lines vertically.

Optical Probe. FOV 80^{o}H x 60^{o}V, (100^{o} diagonal) depth of field 4" to infinity, f# 16, with motion in pitch +45 to -90 degrees, roll $\pm$ 90 degrees; yaw $\pm$ 90 degrees, and zoom 4.5:1. Transmission 48 percent, lens distortion 6 percent, resolution 40 LP/mm @5 percent MTF. The optical field of view was reduced to 60^{o} diagonal by means of the zoom mechanism for the purpose of matching the projector's FOV.

Gantry. The X, Y, and Z travel at the scale factor used for this simulation, yields

x (range, without zoom) = 5.25 miles
with zoom (4x) = 23.6 miles (11.1 feet)

y (lateral travel) = 1.9 miles (4 feet)

z (altitude) = 2.1 miles (4.5 feet)

T-28 Cockpit. With inputs to the computer of throttle, rudder, elevator, aileron, flap and wheel signals, and computer output signals for airspeed, roll, pitch, R/C, altitude, rate of turn, slip indicator and heading. Matches aircraft in performance and flying qualities based on comparison of calculations and aircraft data. Servo performance, or lag characteristics were not measured, from cockpit response through computer input through instrument or visual response.

US Navy Mark VIII Gunsight. As in the T2C aircraft.

Computer. Analog computer, REAC 550, contains mathematical model for T-28 aircraft (reference 7) and the positioning model to slave entrance pupil of optical probe to weapons target. (Reference 8).

Horizon/Sky Projector. A point light source half dome, painted horizon for visual cues for pitch of $\pm$ 90 degrees of travel, roll $\pm$ 90 degrees of travel and yaw of $\pm$ 180 degrees of travel. Variable in brightness 0 to 0.5 FTL (SG = 1.8). Normal viewing = 0.135 FTL.

CRT Projector. Scan rate - 1023 lines/frame, 60 Hz, variable in aspect ratio, video bandwidth 30 MHz, with Thomas 6M75P45 CRT capable of a line width of 0.0035 inches center resolution at a brightness of 15,000 ft Lamberts.

Projection Optics. F.L. 4.4" - f/1.2 $\pm$ 30^{o} FOV, transmission 75 percent minimum, distortion less than 1 percent at 1/2 FOV.

Screen. 10' radius, 360^{o} dome. Gain = 1.8. Projected highlight brightness is 2.6 FTL while resolution is 800 TV lines horizontal with 10 shades of gray.

The subsystems described provide a 60^{o} diagonal, high-resolution insetted display (area of interest) anywhere in the pilot's field of view, within the limitations of the hardware.

The eye position, and arrangement of the CRT projection and sky projector in the dome screen is illustrated in Figure 2.

The Servo Design Criteria is shown in Table I.

Why an area of interest display? It is assumed for this design that there exists a center of interest at any given instant of time to which the pilot's attention will be devoted. The center of interest for the weapons delivery runs would be the target area (point of interest) after crossing the initial (IP). By concentrating the TV system's resolution in this area (60^{o} diagonal) about the pilot's line of sight to the target, current state-of-the-art closed circuit TV systems can be used. The peripheral cues of the horizon and sky orientation can then be presented separately. Figure 3 shows a typical "wander" of the pilot's line of sight during the 90^{o} final turn segment for a 30^{o} Dive Bomb pattern in a RF4C aircraft from reference 9. This reference estimates that a visual display field of view of 240^{o} horizontally and 95^{o} vertically would be needed. A continuous visual display of this size with the necessary resolution (800 x 5 = 4000 lines horizontally) is beyond the state-of-the-art.

The next question is why a two-dimensional model instead of a more expensive three-dimensional model? The various cues to depth can be classified in terms of their dependence

on motion. Many of the most compelling cues such as interposition, relative size and aerial perspective can be considered essentially static, since they are present under both static and dynamic conditions. Others, such as motion parallax and change in vertical perspective can only occur as a result of relative movement between the observer and the object or scene being viewed. Although motion parallax is a relatively minor cue to depth, it provides the essential difference between imagery derived from two- or three-dimensional sources.

A study specifically designed to investigate the role of motion parallax in the perception of apparent depth on a dynamic TV display was conducted by King and Fowler (reference 10).

This study was primarily designed to investigate the perceptual process involved in viewing target imagery by means of a TV display. It was, however, considered desirable from the standpoint of potential application to use representative conditions in terms of flight trajectory, sensor viewing geometry, and ground imagery. Therefore, both constant dive angle and constant altitude approaches were employed at simulated velocities consistent with operational training problems.

The results of this study, to determine the relative effectiveness of two- and three-dimensional image storage media, indicated that movement parallax provides a cue to depth only at very close ranges. It was concluded that for the training problem, which requires simulation of television target imagery, there is little or no advantage in the more expensive three-dimensional storage devices for altitudes above 750 feet.

Since the present study does not require simulated operation below 1,500 ft, it is concluded that the two-dimensional transparency being used is adequate.

The evaluation mission in the simulator was the air-to-surface attack and exercised the skills described previously. Reference 11 provided actual flight parameters for a rocket delivery in a T-28B/D aircraft. It also provided the measures of accuracy needed to validate the pilot-aircraft-sight system performance.

Before each flight, the pilot was briefed on the initial conditions. After each flight, the pilot was given feedback as to his performance. The first three runs were for orientation purposes to familiarize the subject with the device and his expected performance. After completion of these preliminary trials, the subject was given a questionnaire to review. This was done at this time so that the subject was better prepared to observe particular aspects of the simulation. This questionnaire was completed by the subject when he completed all of his flights.

After the preliminary trials and review of the questionnaire, the subject made 10 consecutive flights.

Scoring was obtained by evaluating the course, airspeed, altitude, rate of dive and aircraft attitude time histories and a comparison of the reticle aim point location on the screen with the target location at the rocket release point visually and by computer readout. Details are covered in an unpublished NAVTRAEQUIPCEN in-house Technical Report.

CONCLUSIONS

On the basis of a preliminary evaluation, deficiencies in the simulation hardware can be ruled out as deterrents to the approach since they are engineering changes within the state-of-the-art and the consensus of the five pilots (one pilot flew two missions) was that the concept of using an area of interest display superimposed on a wide-angle projection of the horizon and sky on a spherical screen appeared as a feasible means to achieve air-to-ground training in rocket firing and could possibly be extended to include other types of A/G weapons delivery training.

To verify that this system is indeed low in cost, a comparison to another method is desirable. Perhaps a comparison to the method recommended for the USAF A-10 flight simulator program for A/G in reference 3 would be useful. This is shown in Table 2.

The cost advantage of the NAVTRAEQUIPCEN system is in the 2D model, camera, probe versus, the dedicated computer for CIG in the image generator. For the display, the cost advantage comes from one CRT projector versus many infinity optics windows in the CIG/MOSAIC approach.

From a performance standpoint, the servo, optical and photometric performance of this system exceeds that of other similar projection systems such as the LAMARS at the USAF Flight Dynamics Laboratory and the DMS at NASA, Langley Research Center.

It is recommended that a further evaluation of the concept should be attempted with a larger pilot sample and with a larger field of view area of interest prior to acquisition of units for the fleet. This question of a larger AOI field of view was very recently raised in a new study on the ASPT reported in reference 12.

TABLE 1. SERVO DESIGN CRITERIA

	RANGE TRAVEL	MAX VELOCITY	MAX ACCELER-ATION	POSITION RESOLUTION
Gantry				
Longitudinal	+3.6',-7.5'	20'/sec	3.0'/sec ^{2}	0.0025'
Lateral	±2.0'	20'/sec	3.0'/sec ^{2}	0.0025'
Vertical	+0.0,-4.5"	20'/sec	3.0'/sec ^{2}	0.0025'
CRT Projector				
Azimuth	±180°	10Rad/sec	50Rad/sec^2	NA
Elevation	±90°	10Rad/sec	50Rad/sec^2	NA
Horizon/Background Projection				
Roll	±90°	20°/sec	NA	0.01°
Pitch	±90°	20°/sec	NA	0.01°
Yaw	±180°	6°/sec	NA	0.01°

TABLE II.

COMPARISON OF NAVTRAEQUIPCEN A/G SOLUTION WITH CIG/MOSAIC

System	Method: NAVTRAEQUIPCEN	Method: CIG/MOSAIC
Image Generation	2D model Light Box Optical Probe/Gantry TV Camera Servo Control	CIG Computer
Image Display	CRT Projector Point Light Source Servo Control	Multi CRT's with infinity optics windows

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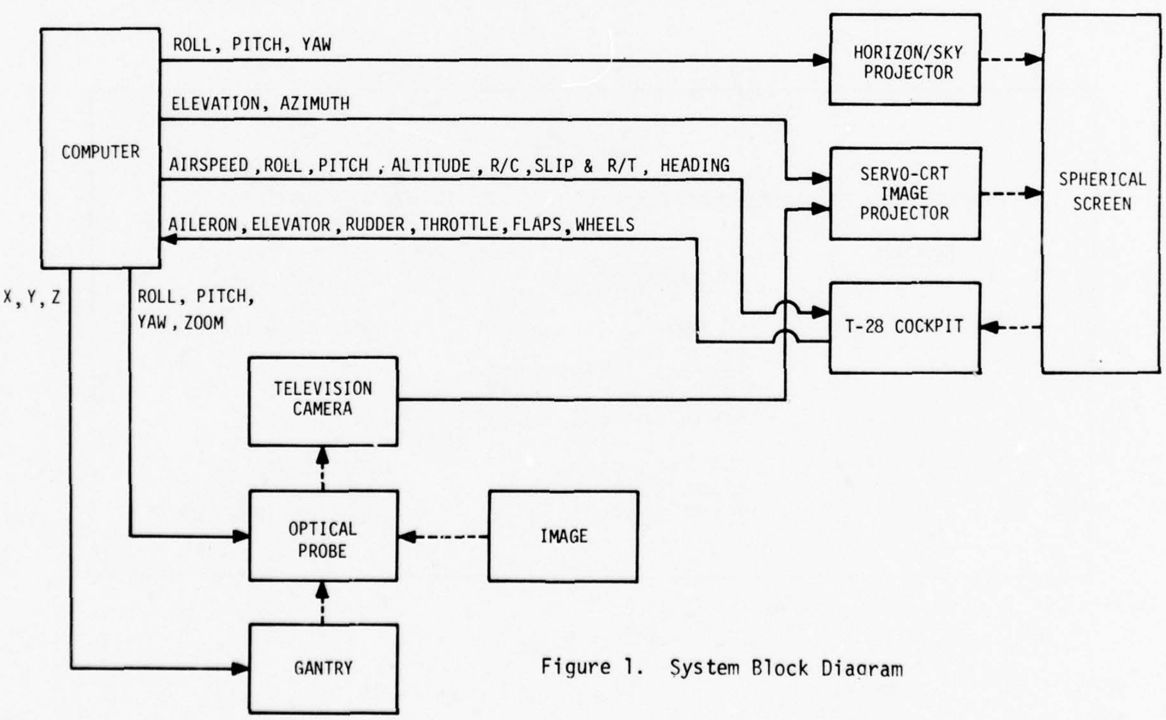

Figure 1. System Block Diagram

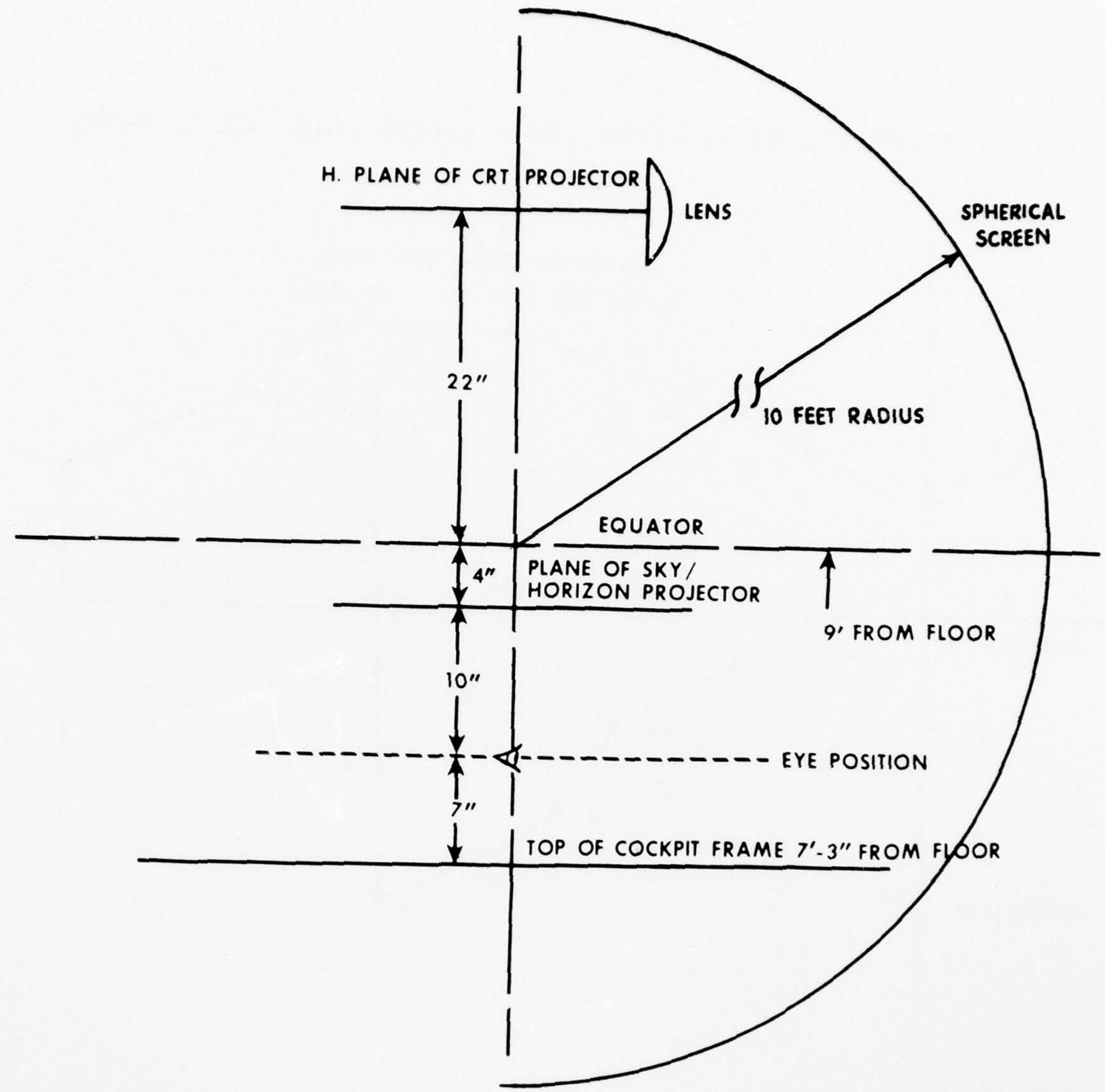

Figure 2. EYE POSITION AND ARRANGEMENT WITHIN SPHERICAL SCREEN

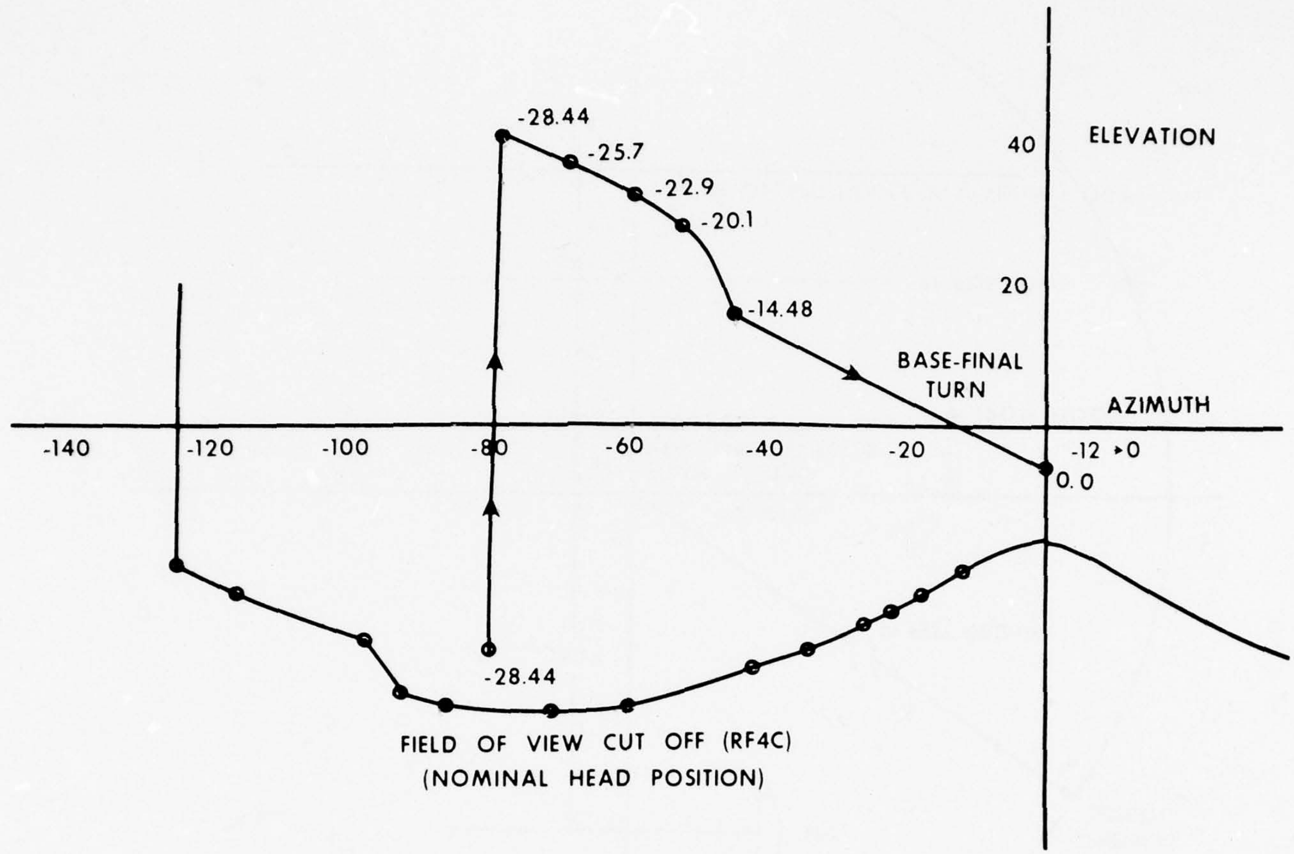

Figure 3. 30° DIVE BOMB - 90° FINAL TURN SEGMENT

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THE CFA CONCEPT, A NEW APPROACH TO TRAINER ENGINEERING CHANGES IN THE FIELD

MOSES ARONSON
Naval Training Equipment Center

INTRODUCTION

The practice of modification engineering or engineering change support as performed at NAVTRAEQUIPCEN is based on the premise that trainer service life extension and/or its conversion to a later configuration is an economical and feasible means of avoiding procuring additional trainers and having to pay the full production costs. This concept is similar to that used by NAVAIRSYSCOM in the conversion of aircraft. (Reference 1). Actually, the NAVTRAEQUIPCEN trainer conversion concept is not new. One of the earliest conversions I recall was that of the Device 2F16 F9F-5 OFT to the Device 2F46 F-1E (FJ-4) OFT in the late 1950s. Some of the facets of modification/modernization/ conversion, such as: what are these changes?, what is the magnitude of the program?, how is it being done?, and where is it going? will be covered in this paper. Let us look at the kinds of changes which need to be engineered.

The configuration and performance of the training device in the field and/or in acquisition can be affected by the following types of changes:

a. Trainer unique hardware/software changes: Those changes to the training device only (trainer hardware and/or software) which correct or improve trainer performance or modify trainer capabilities - better maintainability, improved safety, etc.

b. Changes to the operational tactical digital computer program tapes: Those changes to the operational digital computer programs and tapes which affect weapons system performance in such a way that changes to the training devices' performance may be required.

c. Changes to the hardware of the weapons system being simulated: These changes to the weapons system hardware (or conjunctive hardware/software changes) which affect weapon system performance in such a way that changes to the training devices' performance and configuration may be required.

A trainer hardware/software change categorization system is employed by NAVTRAEQUIPCEN in the trainer configuration management process to define the steps that must be followed for any change consideration. Proper categorization of trainer change requests will permit certain types of hardware/software changes to be implemented quickly without undue time delay or cost, while ensuring that changes with significant functional or performance and documentation impact are thoroughly evaluated prior to implementation. All potential changes to a training device may be assigned any one of four categories as defined in the following paragraphs:

a. Category TA - A change to the trainer software which requires a conjunctive change to the trainer hardware.

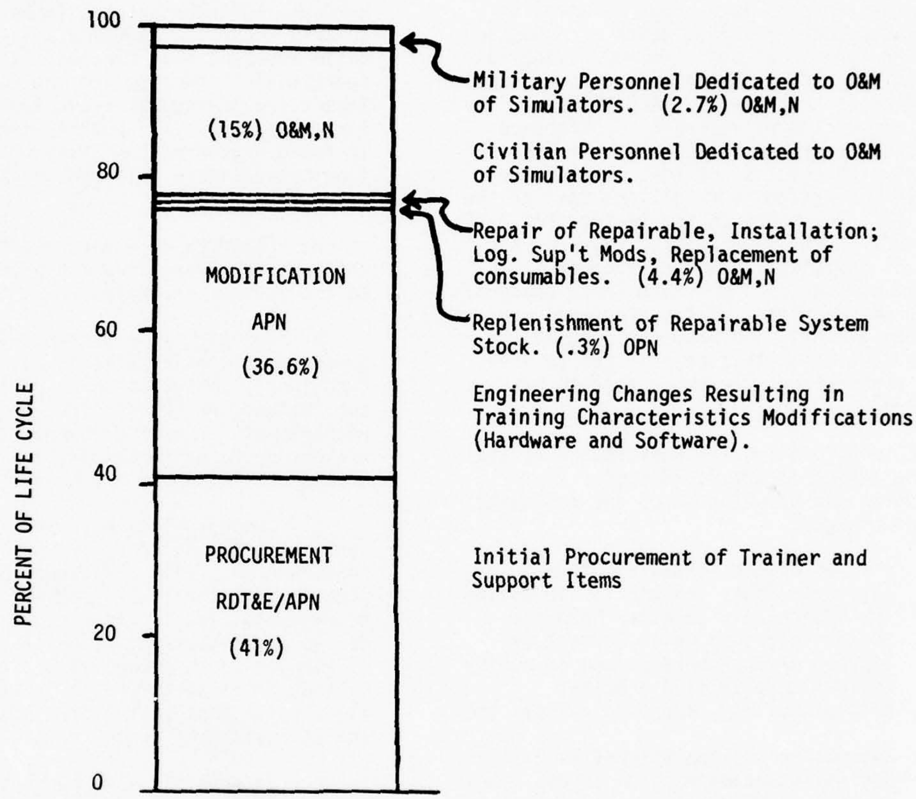
b. Category TB - A change to the trainer software only which affects (1) the functional configuration or performance of the trainer, or (2) requires changes to requirements or user documents such as trainer operator's manuals, training manuals, or trainer maintenance manuals.

c. Category TC - All other trainer software changes. Category TC changes are concerned only with efficient and accurate programming of trainer programs and may require modification of computer program design documentation. Examples of Category TC changes include modifying a computation so that it is performed in a fewer number of steps or so that it requires less storage, and correction of coding errors.

d. Category TD - A change to trainer hardware only which affects (1) functional configuration or performance of the trainer, (2) maintainability/reliability of the trainer, or (3) training improvements/ improved capability/training characteristics.

A second facet of the program is its relative magnitude. Look at the life cycle cost for a highly modified air/warfare class of trainers, the F-4 Aircraft Weapons System Trainers. Figure 1 shows the distribution of trainer costs among initial acquisition, replenishment of repairable supply system stock, operating and maintenance costs and finally the modification costs. The life cycle cost covers the period from about FY 1957 to FY 1982. This end date is not the

obsolescence date for the trainers but the current limit on computation of costs. It can be seen that the initial acquisition cost and that spent on modifications to date are nearly equal (41 versus 36.6%) and that the integrated logistics support and operating costs are about 22% of the life cycle cost to FY 1982. The total life cycle cost from about 1956 to 1982 is estimated at $68¼ million.



NOTE: Funding Identification - O&M,N: Operation and Maintenance, Navy; OPN: Other Procurement, Navy; APN - Aircraft Procurement, Navy: RDT&E: Reasearch, Development, Test and Evaluation, Navy.

Figure 1. Life Cycle Cost of a Highly Modified Air Warfare Trainer (FYs 1957 - 1982 Period).

The next two facets: How is it being done and where is it going will be covered by the balance of the paper.

THE COGNIZANT FIELD ACTIVITY (CFA)CONCEPT

By Department of Defense directives there are three levels of maintenance - organizational, intermediate, and depot. Generally, depot level maintenance organizations are also authorized to perform modifications. The term depot level maintenance would apply equally to an industrial type effort such as that performed by the original equipment manufacturer (OEM) or that performed by an industrial like government activity. The maintenance concept for training devices tends toward two levels - organizational and depot level. This then restricts the level of modifications to two also - the small tasks which do not require special equipment to install the changes or consume more than a few days to install, and the large tasks which require fabrication and assembly of components or changes in digital computer programs beyond the capability of the user or organizational maintenance personnel. The trainer modification engineering project engineer, when investigating a proposed trainer change, must determine the level of resources available to implement the change. Thus, should the change be performed under contract by an industrial concern/software house or by within-the-Navy resources? Pursuing the division of labor further, there is also the question of who has the engineering capability to develop the engineering change and can supply the changes to the integrated logistic support items and to the technical documentation. Further, by directive of the Chief of Naval Education and Training Support (2) specifically assigned levels of authority to perform modification engineering were provided for the efficient use of personnel and resources. These levels are:

Level 1 - Those engineering changes which may be performed by the custodian/using activity providing that the change is less than 40 man-hours (design, debug, installation and documentation); does not affect hardware; does not affect the operational computer programs.

Level 2 - Any change which, through circumstances, cannot be performed by the user as a Level 1 change or which requires hardware, conjunctive hardware/software or operational computer software changes and is less than 1,000 man-hours (design, debug, installation and documentation).

Level 3 - Any change exceeding the limits of Level 2.

In conjunction with these performance levels are the assigned levels for authorizing the changes as follows:

a. Level 1 - At the discretion of the CFA, and in coordination with the custodian/user, approval authority may be assigned to the user to perform those changes defined as Level 1. Changes to be accomplished at this level must be concurred in by the CFA. Documentation developed as a result of a Level 1 change is to be provided to the CFA for coordination with other device users. If coordination dictates no other user requirement for the change, the change can be classified as "local" and may not be incorporated into the baseline documentation by the CFA. Dedicated memory locations will be established by the CFA and utilized for this purpose.

b. Level 2 - All changes exceeding the character and limitations established for a Level 1 change will be submitted in accordance with reference (6). The CFA will provide all services, material, and documentation necessary to perform and support the required changes up to 1,000 man-hours of design, debug documentation and installation. This action will be accomplished within the control parameters established by NAVTRAEQUIPCEN. Changes exceeding 1,000 man-hours may be assigned to the CFA on an exception basis and with CNET SUPPORT concurrence.

c. Level 3 - Those changes exceeding the Level 1 and 2 will be forwarded to the NAVTRAEQUIPCEN for further action in accordance with reference (6). Decisions regarding further implementation will be provided by the NAVTRAEQUIPCEN in conjunction with the appropriate sponsoring agency.

You will notice that this distinction in levels of performance and authority is different from the Naval Air Systems and the former Naval Ordnance Systems Command approach to delegation of engineering effort for service equipment. (References (3) and (4)). For these two Commands, upon completion of equipment production, full engineering responsibility for a specific weapons system is transferred to a field activity; and the field activity performs the same engineering functions and technical coordination that the Assistant Program Manager did at Headquarters. (Reference(5)).

Assignments of limited engineering responsibility of specific trainers were started in 1975 by requesting the CNET SUPPORT field activities to recommend training equipment which, because of geographic location and/or developed experience, can best be assigned to their cognizance. The proposed assignments would provide efficiency in engineering change design effort and would develop organizational expertise in particular units of training equipment. The items included would be characterized by a high-level of complexity and an expected high-incidence rate of engineering changes during its life cycle. The first list of assignments under this concept was issued in July 1977.

Some definitions of terms are now in order so that the concept operation will be easier to follow later on.

a. Engineering Change Support (ECS) or Modification Engineering. The engineering effort necessary to add to or alter the design of an equipment in such a manner or to such an extent as to change its operational capabilities or its design attributes of performance, reliability, maintainability, safety, operability and parts interchangeability or to render it capable of alternative or additional use. The resultant design change includes baseline maintenance of support documentation, computer software, and support material.

b. Cognizant Field Activity (CFA). The field activity of the Naval Education and Training Support Command designated to perform engineering change in support of specifically designated training equipment.

c. Software Support Activity (SSA). An organization designated to perform digital computer software support. Unless specific circumstances require separate consideration, simulator computer software support responsibility is integral to the assignment of CFA responsibility.

d. Computer Software Support. Engineering change support as related to simulator digital computer software, including:

(1) Modifications to computer software as necessary to meet training or logistic support requirements.

(2) Design and development of new computer software as required.

(3) Baseline management of computer software involving the identification, collection, storage, reproduction and distribution of computer programs and associated documentation essential to daily operations.

(4) Computer program housekeeping including assembly/compile operations and those design, development and modification functions concerned with the clarity and efficiency of computer programs.

e. Operational Computer. That portion of the weapons system computer used in training equipment.

ENGINEERING CHANGE SUPPORT AT THE CFA LEVEL

At this point we will focus on the performance of engineering change support which is to be performed at the CFA level. Figure 2 shows the resources available to perform various levels of modification and the relation of the CFA to these levels.

Functions of the CFA. These functions are defined in relation to the deployment date or the Ready-for-Training (RFT) date of a specific training device. Those performed prior to the RFT date are:

a. Assumes assist position to NAVTRAEQUIPCEN during the acquisition process. In this capacity, the CFA will:

(1) Generate and develop the engineering change support plan. This effort is to be accomplished in coordination with the development of the simulator Life Cycle Logistic Support Plan addressed by Reference (7). Details regarding plan format are provided in Volume 1 of the approved outline for the Life Cycle Logistic Support Plan. The Engineering Change Support Plan shall be submitted to CNET SUPPORT via the NAVTRAEQUIPCEN.

(2) Provide inputs in establishing the composition of the data and training required to the NAVTRAEQUIPCEN to ensure inclusion in trainer acquisition budget submissions.

(3) Perform reviews of Training Equipment Change Proposals (TECP) and to provide appropriate comments.

(4) Attend the in-plant test and acceptance of the equipment and may attend design, technical, contract or Fleet Project Team conferences and meetings as requested. Assignment of this responsibility should not be construed as assignment to a specific division/department within the CFA. It would be expected that group travel requirements

are minimized through the use of a single representative to address all interests (Field Engineering Representative support, simulator modifications, etc.) of the field activity whenever possible.

(5) Participate in the configuration Management configuration physical audits.

Those functions performed after the RFT date are:

a. Acts as the single activity for the accomplishment of Level 1 and 2 engineering changes in the field. The changes undertaken are to be performed in accordance with reference (6) and to the limits promulgated by the NAVTRAEQUIPCEN.

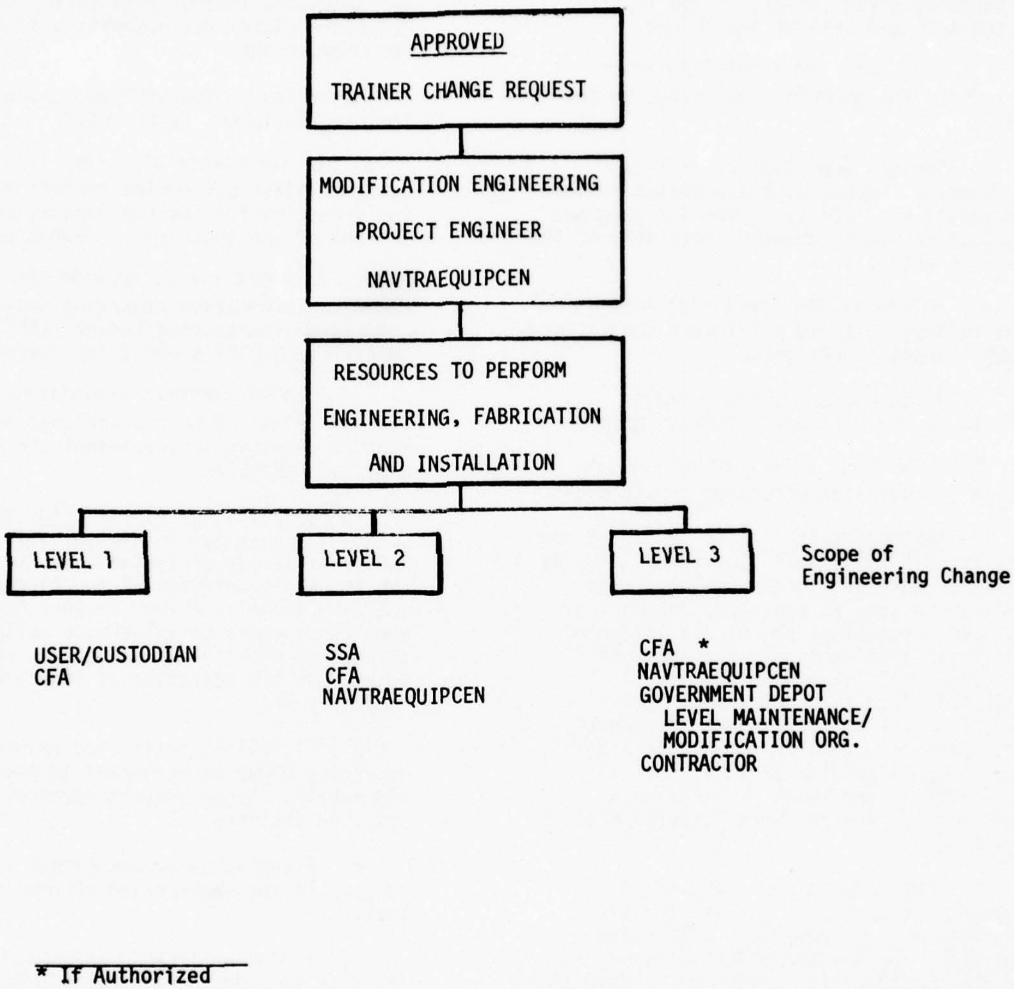


Figure 2. Engineering Change Support Resources

b. Investigates variances in change requirements and recommends appropriate solutions including:

(1) An operational and functional description of the problem and recommeded solutions.

(2) A technical approach to the problem including a definition of the performance effectiveness of the training system with and without the change.

(3) Cost and scheduling information for implementing the change by the CFA.

c. Designs and develops trainer engineering changes with associated revised documentation. (Digital computer programs would be issued as updated iterations of the baseline data.)

d. Maintains the identified baseline reflecting field originated changes and other changes as assigned.

e. Responds to trouble reports related to the engineering change program.

f. Interfaces with user activities in the coordination of change requirements.

NAVTRAEQUIPCEN FUNCTIONS. To assist the CFAs in performing their function the Naval Training Equipment Center will get them involved as soon as practical during the equipment conceptual phase. It is during this phase that necessary planning and direction will take place which will ultimately lead to a successful operational phase engineering change support program. Assignment of a CNET SUPPORT Field Activity as CFA on a simulator or family of simulators is one which constitutes a commitment of the resources/expertise of the entire activity.

a. Upon issuance of the initial planning documents designating the firm requirement for a new item of training equipment, the NAVTRAEQUIPCEN will recommend the appropriate field activity to serve as the CFA and notify the designated activity by formal correspondence. The letter will be released via CNET SUPPORT.

b. Provide Military Characteristics, Program Master Plans and related procurement documentation to the CFA.

c. Provide the CFA with a list of deliverable data items under the terms of the training equipment contract and place the CFA on automatic (identification on DD Form 1423) distribution of selected data items.

d. Provide the CFA information on program and technical conferences and meetings.

e. Solicit CFA for technical data and training requirements and include requirements in subsequent acquisition planning.

f. Provide the CFA with contractor submitted Trainer Engineering Change Proposals (TECP) for comments and recommendations.

After the trainer RFT date, the Naval Training Equipment Center will:

a. In accordance with its assigned mission, provide overall engineering direction for the implementation and control of the engineering change program.

b. As appropriate, provide the CFA with information regarding non-field originated change requirements (AFC's, ORDALT's, SHIPALT's etc.) for review.

c. Provide contract administration services for contractor engineering support services to supplement the CFA's manpower resources.

Responsibilities of the CFAs. As soon as a CFA is designated for a specific training device or family of trainers it is to plan for the implementation of the hardware/software transition from trainer development contractors to in-service activities through an orderly and systematic approach. To achieve the objective of the task it is necessary to:

a. Establish, train, and maintain a dedicated group of personnel to provide engineering change support services for the assigned trainers.

b. Establish a documentation data base to support the engineering change support task.

c. Review applicable ECP's and prepare TECPs in accordance with MIL-STD-480.

d. Respond to field requested modifications in accordance with reference (6).

e. Implement approved changes resulting from approved cost and lead time estimates.

f. Provide task management/coordination for successful completion of the transition.

The success of the transition schedule hinges heavily on three factors: technical competence, satisfactory baseline documentation, and a realistic, agreed upon development contractor phaseout schedule. As such, transitioning of training device support from development contractor to an in-service facility is predicated on:

a. Requested CFA team training being approved and implemented.

b. Required engineering data/documentation being obtained in a timely manner.

c. Phase out of trainer development contractor being accomplished according to the Navy hardware/software transition schedule.

The phaseout of development contractors will be accomplished according to a three-phase schedule agreed upon by the trainer development contractor, training equipment sponsor, NAVTRAEQUIPCEN, and the CFA. The three phases are:

Phase 0 - (1) Provide and assign personnel to the designated family of trainers and through a coordinated training plan, obtain required weapons system technical expertise, (2) Make provisions for the obtainment of a configuration end item documentation data base, (3) Consolidate training plans into a master training plan to be forwarded to trainer sponsor, (4) Review ECPs and modification requests to be accomplished under an in-service effort, (5) Establish a central trainer documentation data base repository, and (6) Coordinate with development contractors and trainer sponsor for orderly and timely transition.

Phase 1 - This phase is a combined effort involving both the in-service activities and the development contractors. It is during this phase that both the in-service activities and contractors coordinate the incorporation of the current engineering changes. Upon completion of these changes, the baseline will be documented and all data will be delivered to the in-service activities for continuation of the engineering change support program.

Phase 2 - In-service Engineering Change Support Program is established and in operation.

I will now explore one facet of this operation in more detail.

Recording of Engineering Changes and Their Distribution. A central repository for hardware/software documentation data for each trainer is established at the NAVTRAEQUIPCEN. The central repository contains and constitutes the master files for the specific trainer ECS task and, as such, will be under the control of the NAVTRAEQUIPCEN. The central respository is designated as the central point for accounting of all data for the assigned specific training equipment. The CFA will have cognizance of working documentation and will forward revised master reproducibles to the central repository for filing as they are generated.

It must be noted that, prior to the issuance of any hardware or software baseline data to effect a contractor modification effort, the CFA will be consulted by NAVTRAEQUIPCEN. This action is necessary since the repository may not house the most up-to-date data due to in-house ongoing modification efforts, lag time inherent in the documentation chain, etc.

Types of documentation to be stored in the central repository are:

a. Reproducibles of engineering and maintenance drawings.

b. Reproducibles of maintenance handbooks.

c. Historical engineering hardware/software reports such as design reports.

d. Instructional material applicable to on-site and factory training courses.

e. Documentation required for support of computer programs and tape update (i.e., Master Tapes, Listings, Computer Hardware Manuals, etc.).

The CFA has generally identified to NAVTRAEQUIPCEN the documentation required to support its hardware/software efforts. Data requirements for specific trainers can be adjusted when recommended by the CFA acting in consonance with representatives of the users.

To ensure the adequacy of the baseline documentation and to ensure its availability for an in-service effort, the following actions will be taken by the NAVTRAEQUIPCEN:

a. Define certain software data per SECNAV Instruction 3560.1.

b. Establish a review process/cycle for both hardware and software documentation between the NAVTRAEQUIPCEN and the CFA.

c. Include the CFA on the appropriate DD 1423s for automatic receipt of documentation.

d. Establish a firm schedule for documentation delivery.

e. Ensure the adequacy of data procured by use of the CFA review process for specific devices.

f. Ensure that trainer sponsor is aware of documentation procurement efforts and the possible resultant problems if it is not procured due to shortage of funds.

The primary categories of documentation affected by software/hardware changes to the specific trainer are:

a. Requirements documents such as trainer system performance specifications.

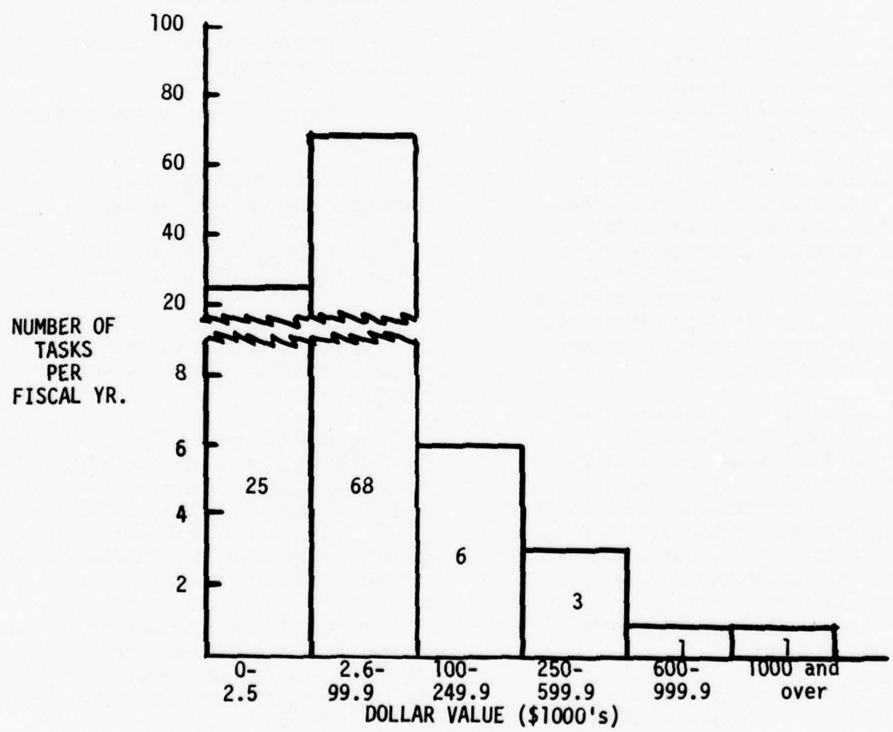
b. Design documents such as computer program performance and design specifications, detailed program and subprogram design documents, design description drawings, trainer program listing, manufacturing and maintenance drawings, Criteria Reports.

c. User documents such as maintenance publications, training manuals, lecture materials and PMS cards.

d. Internal documentation required for the configuration management process.

e. Test plans and procedures.

Maintenance of trainer system specifications will be the responsibility of the NAVTRAEQUIPCEN as provided for in MIL-STD-480. Control of working master design documentation is the responsibility of the CFA. In addition, the CFA will identify and describe the impact of trainer hardware/software design changes on all documentation.



MODIFICATION PROGRAM BY DOLLAR VOLUME OF TASK
(5 YEAR AVERAGE) AS OF FY 77
FOR ALL LEVELS OF EFFORT

Figure 3.

Updating user documentation such as trainer maintenance manuals, training manuals, lecture materials will be the responsibility of the NAVTRAQUIPCEN who is also responsible for integrating software design change information into this user documentation. Test plans and procedures will be developed and updated by the CFA as required to support applicable design, integration, verification and acceptance testing responsibilities. Approval of these documents will be the responsibility of NAVTRAEQUIPCEN. The computer programs will be revised by the CFA to reflect changes made to the program. Patches will not be issued. The revised reassembled computer program will be incorporated into the change kit for distribution. Revised masters will be provided to NAVTRAEQUIPCEN for approval and storage in the master repository.

MODIFICATION WORKLOAD

What is the magnitude of the modification workload? If we take the statistics for a recent year, we can see the distribution of effort. Figure 2 showed the performers by level of effort. The next figures give some specific directions for the effort. Figure 3 shows the distribution of dollar volume of modification effort. Shown is a 5 year average through FY 1977 and indicates that most modification tasks are in the under $100,000 value. The number in this dollar value range is actually larger as modifications costing $5,000 or less for aviation trainers or $20,000 or less for surface and sub-surface trainers may be lumped together and authorized in a group as a single task.

Another way of looking at the workload is by warfare areas. Table 1 shows the numbers of tasks assigned, irrespective of funding levels, to the CFAs. The number of modification tasks performed for aviation trainers greatly exceeds those assigned for all the other warfare areas. This is only natural since presently air warfare trainers represent 77% of all

TABLE 1. MODIFICATION TASKS BY WARFARE AREAS ASSIGNED TO CFAs IN FY 1978

WARFARE AREA	NUMBER OF TASKS
AIR	218
SURFACE	69
SUBSURFACE	28
LAND (MARINE CORPS)	6
TOTAL	321

MODIFICATION TASKS BY WARFARE AREAS ASSIGNED TO CFAs IN FY 1978

trainers in inventory. While no discussion has been presented of the implementation of trainer digital computer program changes, Table 2 shows the distribution of effort in the CFAs between hardware and software changes. This figure shows only the training characteristics modifications (two of the three types described earlier) but these would represent about 90% of all modifications. It can be seen that for air warfare trainers hardware changes still predominate probably due to the nearly constant introduction of weapon system hardware changes while in the surface-subsurface area the software changes are a slight majority. This might be due to the refining of ocean environmental models or SENSOR/TARGET characteristics as well as increasing the capability of the instructor's station and the trainer as a whole. Future trends in workload can be looked at two ways by yearly trends and product mix. Table 3 shows the growth in the total modification engineering program and the in-house or CFA share of the program. Future years funding has not been definitized but it looks like it will grow. Note that the in-house share of program is not increasing as rapidly as the total program. The other way to look at the program is by product mix. Table 4 shows the present distribution of training equipment in use by warfare area and the projected mix in Fiscal Year 1984 based on present acquisition trends. You can see that the total share of nonaviation devices has grown from 23% to 36.5% of total inventory. What does this mean on workload? Table 2 showed that the surface and subsurface trainer modification was software change intensive, thus the conclusion could be that by Fiscal Year 1985 or so the major CFA labor effort will be in software as opposed to the current hardware intensity.

WARFARE AREA		HARDWARE	SOFTWARE
AVIATION		82.3 Man-Years	51.5 Man-Years
SURFACE-SUBSURFACE		9.4	10.8
	TOTAL	91.7 Man-Years	62.3 Man-Years

TABLE 2.

TRAINING CHARACTERISTICS MODIFICATIONS ONLY:
DISTRIBUTION OF EFFORT BETWEEN HARDWARE
AND SOFTWARE (FY 78)
ASSIGNED TO CFA's

FISCAL YEAR	DOLLAR VALUE ($1000's)	IN-HOUSE (CFA) SHARE ($1000's)
1978	$15,000 (Approximate)	$3,760 (Approximate)
1977	11,938	3,013
197T (1/4 Year)	1,638	636
1976	5,475	2,742
1975	4,166	2,485

TABLE 3.

TOTAL MODIFICATION ENGINEERING PROGRAM TREND
(ALL LEVELS OF EFFORT)

	EQUIPMENT IN USE FY 77	ANTICIPATED AGGREGATE FY 84
AIR	77.0%	63.5%
SURFACE	15.3%	25.4%
SUBSURFACE	7.7	11.1%

TABLE 4.

DISTRIBUTION OF IN-USE ASSETS BY WARFARE AREA CURRENTLY AND IN FY 84

CONCLUSION

In conclusion, we can make a number of general statements about the Modification Engineering Program and the CFAs. The Modification Engineering Program is an approach used by the NAVTRAEQUIPCEN to extend the life of current training equipment and conform them to the everchanging operational weapons systems they provide training for. On a specific trainer life cycle cost comparison, the modification costs can nearly equal the initial acquisition costs but are spread over a larger time frame. Most modification tasks are under $100,000. The CFAs provide an engineering service to the NAVTRAEQUIPCEN during the acquisition phase and after RFT take on the major engineering change responsibilities for small changes. The CFAs' workload will increase but not at the same rate as that of contractor performed modification tasks. And finally, the CFAs expand the NAVTRAEQUIPCEN in-house engineering labor base.

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THE ROLE OF SIMULATION IN LARGE-SCALE ISD

DR. G. P. KEARSLEY AND DR. A. L. O'NEAL
Courseware Incorporated

The scope and complexity of major Instructional Systems Development (ISD) programs and the sophistication and detailed definition of the particular ISD models being utilized in the military have greatly increased in the last few years. The advanced planning and day to day management required for such programs has become commensurately more difficult and complex. The interactions among the many resources, personnel, and scheduling requirements involved increases the difficulty of identifying specific sources of problems and responding to them without causing other problems elsewhere. In response to this management challenge, interest is greatly increasing in comprehensive, real-time integrated information management systems for ISD which incorporate a variety of flexible management projection and simulation capabilities. It is becoming essential to give managers the tools to test the impact of their decisions before they commit themselves to courses of action whose consequences are not completely understood. This paper discusses the nature and implications of such simulation capabilities in ISD program management with particular reference to two projects recently completed under contract to Defense Advance Research Projects Agency (DARPA) and the Naval Training Equipment Center (NAVTRAEQUIPCEN).

In the context of ISD management systems, simulation capabilities provide two major functions: projection of existing trends and modeling of changes to the present system parameters. Thus, it is possible to determine the estimated start/finish dates for any/all tasks or events in the ISD program. It is possible to ask such questions as "with current personnel and resource conditions when will the course be finished?," "how much of each skill or other resource available will be used?," or "how much time of person X can be released while maintaining the projected completion date?" If a planned media alternative is written out for some reason, what will be the effects on the program? For example, suppose a course being developed has 40 videotapes specified but the project is now running over budget. It would be possible to explore the possibility of replacing those videotapes with a more economical media such as slide/tapes to see what effect they will have on budget, resource utilization, and project completion dates. Another possibility is to furnish the system with a desired completion date and calculate the conditions necessary to meet that deadline including all resource needs. With these types of "what if" capabilities, it is possible to determine the real cause of problems or delays. For example, it may be found that the planned hiring of two more instructional psychologists will have no effect on production rate or completion deadline. With the help of some exploration using the simulation capabilities, it might be revealed that the real bottleneck is in review and editing personnel.

Simulation capabilities such as those described above have been provided in two ISD management systems developed by Courseware Inc. The Author Management System (AMS) is an operational prototype system developed under contract to DARPA implemented on minicomputer in BASIC (1). It provides a set of management support capabilities for the design, development, production, and ongoing curriculum maintenance phases of ISD. It tracks the exact stage of completion of each identified course component and monitors the workloads, current assignments and deadlines of all personnel. A major built-in feature of AMS is the generation of reports which indicate estimated and projected dates of completion or resource expenditures. For example, Figure 1 shows a total course projection report indicating estimated projected resource utilization and Figure 2 illustrates a manpower projection report which indicates overall projected project completion date. If the amount of time estimated to be required of a particular class of personnel on some project activity is altered, it is possible to see the overall effect on project costs and completion date. Thus, AMS allows the investigation of the effects of salary increase, addition or loss of specific personnel or classes of personnel, budget cuts, changes in syllabus or media, changes in project procedures, or changes in the time frame available for developments.

The Computer-Aided Training System Development and Management (CATSDM) project funded by NAVTRAEQUIPCEN (2) has resulted in the specification of a system of programs and databases to support all phases of the ISD process in the military training context. These programs are organized according to

**** TOTAL COURSE PROJECTION ****
USING PRESENT RATE OF COMPLETION
MONDAY, MARCH 6, 1978

		UNITS		MONEY		
RESOURCE		ESTIMATED	PROJECTED	ESTIMATED	PROJECTED	RATE
01	INSTRUCTIONAL PSYCHOLOGIST	85.00	85.00	1719.55	1719.55	1.000
02	SUBJECT MATTER EXPERT	653.00	653.00	8044.96	8044.96	1.000
03	AUTHOR	511.50	511.50	629.15	629.15	1.000
04	TYPIST	213.00	213.00	928.68	928.68	1.000
05	INSTRUCTIONAL TECHNOLOGIST	82.00	82.00	1260.34	1260.34	1.000
06	EDITOR	317.00	317.00	2396.52	2396.52	1.000
07	ARTIST	944.50	944.50	13733.03	13733.03	1.000
08	PRODUCTION MANAGER	46.50	46.50	609.62	609.62	1.000
09	WORD PROCESSOR	201.50	201.50	1904.18	1904.18	1.000
10	PASTER-UPPER	77.50	77.50	508.40	508.40	1.000
11	MEDIA EXPERT (S/T)	120.00	120.00	894.00	894.00	1.000
12	SCRIPTWRITER	310.00	310.00	4163.30	4163.30	1.000
13	PHOTOGRAPHER	100.00	100.00	345.00	345.00	1.000
14	MEDIA EXPERT (S/D)	89.00	89.00	1098.26	1098.26	1.000
15	LYRICIST	70.00	70.00	241.50	241.50	1.000
16	COMPOSER	70.00	70.00	535.50	535.50	1.000
17	CHOREOGRAPHER	301.00	301.00	1369.55	1369.55	1.000
18	DIRECTOR	91.00	91.00	576.94	576.94	1.000
19	KAZOO PLAYER	91.00	91.00	395.85	395.85	1.000
20	SINGER	91.00	91.00	696.15	696.15	1.000
21	DANCER	91.00	91.00	303.03	303.03	1.000
22	DEC	186.00	186.00	4151.52	4151.52	1.000
				46505.03	46505.03	

ORIGINAL ESTIMATE: 46505.03 DOLLARS
PROJECTION AT PRESENT RATE: 46505.03 DOLLARS
WHICH IS 0 DOLLARS DIFFERENT FROM ESTIMATE

Figure 1.

***** MANPOWER FOR COURSE COMPLETION *****
USING PRESENT RATE OF COMPLETION
TUESDAY, MARCH 7, 1978

RESOURCE	-- HOURS TO COMPLETE THE PROJECT -- ESTIMATED	PROJECTED	AVAILABLE	RATE
01 INSTRUCTIONAL PSYCHOLOGIST	79.00 -	282.82 -	3102.00	3.580
02 SUBJECT MATTER EXPERT	620.00 -	1264.80 -	2831.28	2.040
03 AUTHOR	511.50 -	511.50 -	1942.98	1.000
04 TYPIST	213.00 -	213.00 -	2509.80	1.000
05 INSTRUCTIONAL TECHNOLOGIST	82.00 -	82.00 -	2346.24	1.000
06 EDITOR	317.00 -	317.00 -	1646.88	1.000
07 ARTIST	944.50 -	944.50 -	1229.52	1.000
08 PRODUCTION MANAGER	46.50 -	46.50 -	879.84	1.000
09 WORD PROCESSOR	201.50 -	201.50 -	817.80	1.000
10 PASTER-UPPER	77.50 -	77.50 -	710.64	1.000
11 MEDIA EXPERT (S/T)	119.00 -	505.75 -	924.96	4.250
12 SCRIPTWRITER	310.00 -	310.00 -	902.40	1.000
13 PHOTOGRAPHER	100.00 -	100.00 -	1128.00	1.000
14 MEDIA EXPERT (S/D)	86.00 -	465.26 -	479.40	5.410
15 LYRICIST	70.00 -	70.00 -	676.80	1.000
16 COMPOSER	70.00 -	70.00 -	225.60	1.000
17 CHOREOGRAPHER	301.00 -	301.00 -	338.40	1.000
18 DIRECTOR	91.00 -	91.00 -	141.00	1.000
19 KAZOO PLAYER	91.00 -	91.00 -	338.40	1.000
20 SINGER	91.00 -	91.00 -	180.48	1.000
21 DANCER	91.00 -	91.00 -	112.80	1.000
22 DEC	186.00 -	186.00 -	203.04	1.000
23	0.00	0.00	---NA---	0.000
24	0.00	0.00	---NA---	0.000
25	0.00	0.00	---NA---	0.000
26	0.00	0.00	---NA---	0.000
27	0.00	0.00	---NA---	0.000
28	0.00	0.00	---NA---	0.000
29	0.00	0.00	---NA---	0.000
30	0.00	0.00	---NA---	0.000
31	0.00	0.00	---NA---	0.000
32	0.00	0.00	---NA---	0.000
33	0.00	0.00	---NA---	0.000
34	0.00	0.00	---NA---	0.000
35	0.00	0.00	---NA---	0.000
36	0.00	0.00	---NA---	0.000
37	0.00	0.00	---NA---	0.000
38	0.00	0.00	---NA---	0.000
39	0.00	0.00	---NA---	0.000
40	0.00	0.00	---NA---	0.000

ASSIGNMENTS REMAINING TO COMPLETE: 2046
TASKS REMAINING: 1285

ASSUMING AVAILABLE SKILLS AND
EXCLUDING ANY SKILLS PRESENTLY NOT AVAILABLE
OR NOT APPLICABLE (---NA---). THE PROJECTED
DATE OF COMPLETION IS WEDNESDAY. SEPTEMBER 13. 1978

THE THREE SKILLS TAKING THE LONGEST TIME
WITH THE PRESENT PERSONNEL ARE. IN ORDER: 14 22 17

Figure 2.

five major ISD phases: analysis, design, development, implementation, and evaluation. Simulation capabilities are specified in all five phases; however they are most fundamental to the programs in the design phase. For example, the Media Selection Program assists in identifying the optimal delivery medium and all alternative acceptable media for each objective in the curriculum. When available instructional media are not clearly defined, this program can project possible alternatives. In cases where media changes must be made, the program can make recommendations based upon the instructional requirements of the objectives. For example, the Syllabus Development Program assists the ISD team in sequencing and organizing the objectives, developing course maps or class schedules. The simulation capabilities involved here are the projection of periods of peak resource utilization or of the revised syllabi necessitated by an instructional resource (e.g., instructor, trainer, classrooms) being unavailable.

Thus, AMS and CATSOM illustrate how simulation can be helpful at many different levels of the ISD process. This includes the level of project administration in terms of the effects of changes in resources on budgets and deadlines; the level of curriculum and instruction where the varying effectiveness of different lesson plans, media selections, or teaching strategies can be explored; and the level of ISD models or principles which involves the use of historical data from past ISD efforts to assess the validity of proposed ISD analysis design, development, implementation, or evaluation models before they are applied to real projects.

The effectiveness and validity of these types of simulation capabilities will be highly dependent upon the adequacy and completeness of the current and historical data bases. Thus, the current data base must provide an accurate picture of available resources, status of the development of project components, specification of ISD event sequences and their resource/personnel requirements and identification of the roles and skills of the ISD team. The historical data base represents a cumulative record of personnel efficiency, resource utilization, instructional effectiveness of part syllabi and media selections, and the amount of time that any ISD task has actually taken, both in specific instances and across all occurrences. The historical data base is clearly a very crucial factor in producing valid simulation results; it is also a feature which is most often lacking in past ISD efforts. Indeed, until the sort of management planning capabilities discussed above are available, there has been no practical way to collect such detailed historical data on ISD efforts.

There are a variety of general-purpose and even of training-program-specific simulation systems becoming available. These are currently finding their most effective use in planning and training support requirements analysis of major programs. Among these are such program/systems as MODIA (3), L-COM (4), and DOSS (5). These programs, while they reflect varying degrees of sophistication and power, do not offer the solutions and support required for the real-time or on-line management of major ISD activities. Characteristics of the management systems which are required now, and which will be required in the near future, are fairly straight forward. Due to the compressed time frames of most ISD activities and the great number of short-term deadlines and simultaneous activities being undertaken, the system must be real-time and should support the capability for routine data collection, project monitoring, and report generation activities at the same time that they support the types of management simulation activities discussed here. Simulation capabilities being added to the new generation of training systems such as the Navy VTS (6) or the Air Force AIS (7) will probably meet these requirements.

These ISD simulation systems must have a number of essential features. One important characteristic of these systems is that they should be human engineered for users such as project managers, secretaries, psychologists and ISD team personnel, not computer programmers. A counter-example here might be MODIA, one of the most powerful and flexible of the simulation/projection systems currently available. The use of MODIA requires at least two expert teams of personnel. One team of personnel should be experts in the system being analysed and the other team must be specifically trained and experienced in the use of the MODIA program itself. In other words, this system, while powerful and sophisticated is not human engineered to the class of users involved in most ISD activities.

It is also important that the simulation and planning capabilities be integrated into a comprehensive ISD management system such as the CATSDM project. Attempting to add simulation or modeling capabilities in a piecemeal fashion can result in a Tower of Babel from a programming and data base organization standpoint and typically makes

the system cumbersome and inefficient. This argues for the general point that simulation must eventually be accepted as an integral component of the ISD management process.

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MYOELECTRIC FEEDBACK CONTROL OF ACCELERATION INDUCED VISUAL SCENE DIMMING IN AIRCRAFT TRAINING SIMULATORS

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This study is being conducted under contract with the Air Force Human Resources Laboratory

SUMMARY

Visual dimming experienced during aircraft maneuvering accelerations is an important information source for the simulator pilot. A method for integration of the man with the simulator is demonstrated using computer-based physiologic models and readily measured electromyographic signals arising from the straining maneuver. This technique forces active participation and energy expenditure by the simulator pilot similar to the requirements of the aircraft pilot undergoing acceleration.

Simulation models are developed which relate the effects of the G suit, straining techniques and the cardiovacsular response system to a single protection variable (PV). The PV signal drives a predictive visual field model derived from analysis of the retinal circulation in the eye. Allowances are made for subject variation and cockpit seating configurations.

The model produces accurate predictions of short-term G_Z tolerance in its present form and with slight modifications can be adapted to include energetic costs for long-term accelerations.

INTRODUCTION

The aircraft pilot in causing his plane to change its velocity vector places himself in a changing acceleration environment. At certain levels, durations and directions of acceleration the visual field of the pilot is diminished, possibly to the point of blackout. At greater levels and durations unconsciousness may occur. The greatest level at which the pilot still has vision is referred to as his acceleration tolerance. In flight, he has both protective measures and devices which improve this acceleration tolerance. Straining and grunting during tight turns were practiced by German pilots prior to World War II as a means of improving tolerance. This practice led to the development of the M-1 maneuver. Other techniques using posture changes, restraint systems, and body position have been well explored. Present G protective techniques (principally the G suit) attempt to prevent the consequences of the peripheral pooling of the blood during acceleration by the application of a suitable counter-pressure.

The simulator pilot does not have to contend with the actual acceleration forces in his ground maneuvers. The G suit and the G seat provide a tactile feel of the acceleration, however the internal visual field of the simulator pilot is not impaired nor does he need to strain. The muscular straining requirements can be included in the simulation scenario so that the pilot experiences a more realistic training situation in the simulator. Thus, it is possible to create an accurate representation of visual field dimming and fatigue onset for the simulator pilot. The G effects can be simulated realistically by integrating the man with the simulator system. This integration can be made by a combination computer-based dynamic physiologic models and easily instrumented myoelectric feedback.

PHYSIOLOGIC FACTORS OF ACCELERATION TOLERANCE

The physiologic changes caused by acceleration have been reported on extensively in research literature. The two widely recognized factors which contribute to pilot impairment in maneuvering aircraft are fatigue and visual dimming. These two factors can be included in a simulation model system to enhance the reality of simulated air combat.

The cardiovascular system has received the greatest attention in acceleration stress studies as it provides an easily measured set of symptoms. The limiting factor in the cardiovascular system from the viewpoint of combat maneuvering stress is the reduction of blood pressure at eye level and subsequent loss of vision. The pressure gradient changes caused by the G loading and blood pooling are, of course, the major contributing factors which reduce the pressure available at the eye and in more severe cases at the brain. Counteracting the reduced pressure is the primary purpose of straining maneuvers, the M-1 and L-1. Blood pooling in the lower body is reduced by use of the G suit. The factors then, which define an operating limit in the cardiovascular system, are related directly to the blood pressure response characteristics in the 3-15 second time frame.

Another area of interest in the physiologic response to G stress is the time period beyond 15 seconds. Once the pilot has passed a G stress level which represents his relaxed tolerance, he must expend energy in straining to increase blood pressure and, thus, maintain vision. The amount of energy expended in the blood pressure maintenance task is a factor of his straining efficiency and the magnitude of the G difference between his relaxed tolerance and the current G stress level. It can be speculated that the time endurance limit is a factor of the individuals available energy pool minus the energy used in visual maintenance. When the energy pool is diminished to a certain level, the fatigue limit is reached. One purpose of the proposed simulation system is to cause the simulator pilot to be energetically loaded in the same manner as the aircraft pilot.

SYSTEM STRUCTURE

The system presented on the following pages represents the results of partitioning the complex physiologic system into linear sub models. Each sub model is explored and developed in detail based on a common protection variable PV which is related physiologically to system blood pressure. The blood pressure models are then finally combined in a systematic paradigm which provides the driving values for the visual field response model. There are four seperable models which result from the partitioning process; the cardiovascular model, the straining model, the G suit model, and the visual field model.

The cardiovascular response model is represented by a dynamic linear transfer function which corresponds with the response of the pilots blood pressure to acceleration. The governing factor in pilot response to acceleration is the onset of greyout and blackout. These visual problems are directly related to the available blood pressure at eye level. This model output provides a dynamically responding signal which is equivalent to nominal eye level blood pressure values for a human undergoing the equivalent acceleration, G(t), profile.

The straining simulation model accounts for the G tolerance enhancement which is afforded by a properly executed M-1 maneuver. The purpose of the straining or M-1 maneuver is to increase the blood pressure delivered to the eye. Proper performance of the maneuver requires that the abdominal and upper torso muscles be tensed isometrically and that expirations should be made against a closed glottis. The result is an increased intrathoracic pressure and increased blood pressure at the eye. Proper application of the straining maneuver results in the appearance of myoelectric signals on the skin surface. These biologically derived signals are processed by the model to generate a straining protection variable PV_s which represents the increased blood pressure due to the M-1.

The pressurized G suit is an important protective garment used to increase the individuals tolerance to $+G_z$. The suit uses pressurized bladders to press against the legs and lower abdomen. The external pressure inhibits displacement of the blood volume to the lower extremities thus insuring a better supply to the heart during acceleration. The suit must be inflated by the G valve to a predetermined level to be effective. The simulation model accounts for the required pressure level and uses the actual suit to provide the necessary dynamics. The suit pressure is compared with the required schedule and a protection value is generated by the model.

The dynamic visual field model is developed to be readily implemented in a

simulation system. The visual field model reacts to PV level inputs from an external source and produces a dynamically responsive signal which predicts the expected visual field of a pilot undergoing the identical G profile.

The required dynamic model of pilot visual response to G_z assembled as a superposition of the separate models. The completed system algorithms provide the means for implementation in aircraft training simulators. The integrated system is structured according to Figure 1.

Pilot commands (1) thru the simulator aircraft dynamics cause changes in the aircraft velocity vector. Vector changes which result in a linear component of $+G_z(t)$ are used to drive the cardiovascular model (3). In addition the $G_z(t)$ signal causes the pilots G suit (4) to inflate according to a preselected schedule. The effect of the proper suit inflation is to increase the value of the protective variable within certain limits. The sum of these signals (5) is added with a random signal related to individual variation. The resulting PV signal drives the visual field model. The instrument panel and the view screen are then dimmed according to the output of the model (6). The pilot senses the size and brightness changes and has the option of reducing his aircraft maneuver intensity or increasing his G tolerance level by performing an M-1 maneuver. If he initiates the M-1 maneuver, the straining model processes the myoelectric activity from his skin surface and modifies it with a signal related to the straining interval (7). If he performs the appropriate action, the model responds with an additive value of PV (8) and his visual scene is enhanced. The separate models are described in the following sections.

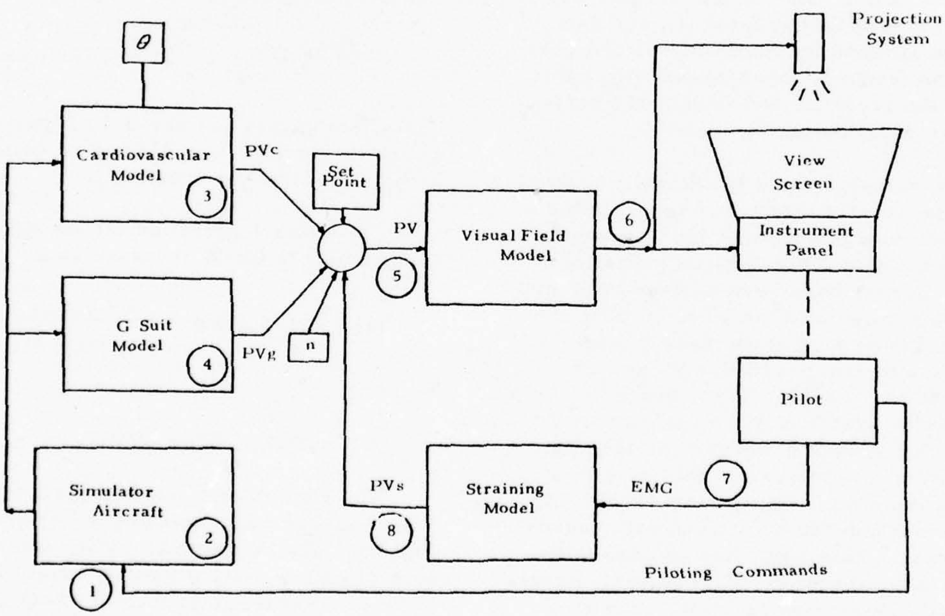

Figure 1. System Diagram

THE CARDIOVASCULAR MODEL

Human tolerance to long-term $+G_z$ acceleration is normally measured in terms of visual loss (blackout) and unconsciousness. Both of these tolerance end points are related to the ability of the cardiovascular system to deliver oxygenated blood at adequate pressure to the retinal and cerebral regions. The distribution of the blood in the body also changes as the acceleration pools blood in the lower parts of the body and lungs. There is, therefore, less available blood to circulate and a lower oxygen content because the lungs do not operate as efficiently.

There are two cardiovascular systems which are dynamically involved in the process of blood pressure maintenance while the human is undergoing $+G_z$ acceleration. The hydrostatic system which is related to classical fluid mechanics is responsible for the reduced retinal perfusion pressure at the eye and eventual loss of pressure at the cerebral level. The orthostatic system is related to blood pooling in the lower body with a concomitant reduction to venous return to the heart. The cardiovascular system has self-regulatory feedback systems which are affected by blood volume and pressure. The feedback mechanisms attempt to regulate the pressure and flow characteristics of the cardiovascular system.

Both animal analogs (principally canine) and human experimentation have led to the current knowledge about the blood pressure response to $+G_z$. Canine blood pressure response curves have been derived by Knapp with maximum gain in the 30 to 60 mHz range. Koushanpour et al. show a first order transfer function with a 20 second time constant. Levison has proposed a second order system for the canine carotid reflex with a natural frequency of 42 mHz. Examination of Gillinghams data as a Bode plot indicates that a single zero double pole transfer function can be applied with reasonable results. This study has adopted a like function to represent the Pressure-G_z acceleration (P-G) transfer function. The frequency range of interest is restricted to f 200 mHz as the physiologic responses of interest to long-term maneuvering accelerations falls within this range. The generalized transfer function is:

$$P(s) = \frac{K_1(1+a_1 s)}{1 + b_1 s + b_2 s^2}$$

Values are selected for a_1, b_1 and b_2 as compromise values from the literature and Gillinghams response curves. The system lead term is selected at f_z = 30 mHz and the system response is selected as a complex pole at fp = 70 mHz and $\xi = 0.7$. For these breakpoints the values of $a_1 = 5.31$, $b_1 = 3.23$ and $b_2 = 5.17$.

The blood pressure transfer function gain at eye level is directly affected by the seat back angle, the direction of the local vertical G axis and the anatomic offset of the eye. The static pressure at eye level is calculated from

$$Pae = Pa - .77\, he \cos\theta\, G$$

where Pae and Pa represent pressure at the eye and heart level respectively, and the effect of the seat angle offset is implemented by a modification of the cardiovascular transfer function gain $K_1(\theta)$. The transfer function gain is then given as

$$\frac{Pae - Pa}{G} = K_1(\theta) = -.77\, he \cos\theta.$$

The offset angles are shown in Figure 2 where the seat back is defined as coincident with the physiologic z axis P_z.

For normal operation the transfer function from G to blood pressure takes the form

$$P(s) = -21.4 \cos\theta \frac{1 + 5.31s}{1 + 3.23s + 5.17s^2}.$$

THE G SUIT MODEL

The history of G suits dates from World War II and is well reviewed in recent monographs. The wraparound CSU-3/P cutaway-type of anti-G suit, presently used by the U.S. Air Force, improves blackout tolerance in the $+G_z$ vector by about 2 G above resting tolerance.

The relationship between the G suit pressurization and effective blood pressure

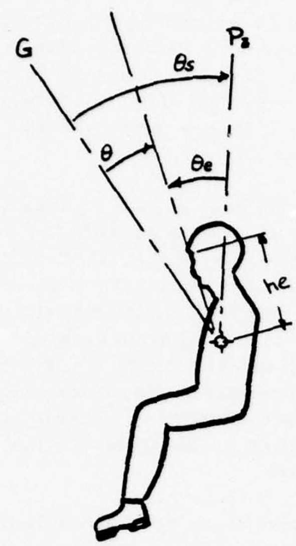

Figure 2. Physiological Axes with Anatomical Offsets

θs - seat angle   θe - retinal angle
Gz - local gravity Pz - Physiologic z axis
he - eye height above aorta θ - G axis offset

increase at eye level is highly complex. The physiological mechanism of action of anti-G suits was originally established on the Toronto centrifuge and at the Mayo Clinic and has been summarized by Wood and Lambert. They show that inflation of a G suit at 1G produces an initial increase in arterial pressure, followed by an almost immediate decrease in heart rate probably due to a depressor reflex originating in the carotid sinus and aortic areas.

McCally has shown that the G suit does not provide protection unless the suit is inflated to at least 80 mmHg. In effect, the pressure difference between the suit bladder and the hydrostatic blood pressure in lower body must be such that the suit pressure is greater to effect a protection function. The same reasoning is used in developing the simulation model. The suit pressure must be within acceptable pressure tolerance or it will afford no protection value.

The protective G suit garment contains air tight bladders which are filled with pressurized air delivered from a G sensitive mechanical valve. The pressure delivered by the valve is a function of the current G level.

G suit inflation does begin when the valve has reached a level of 1.5 - 1.7 G. After this point the pressure output is a linear function of G with a value of approximately 75 mmHg per G. The air bladders, the suit air feed hose and the containing garment represent a dead space which introduces a time delay into the pressure system.

The blood pressure G suit model assumes a nominal 2G or equivalent 42.8 mmHg increase for a properly inflated suit. For a suit with lower pressure than designated the increased G protection and equivalent blood pressure value decay linearly to 0. The model is driven by a delta P (ΔP) representing the pressure difference between the standard suit pressure curve and the actual suit pressure. When suit pressure is equal to or greater than the standard curve value, full protection is assumed. When the suit pressure is less than required by the standard curve, the protection value is lowered. When the pressure differential is greater than 80 mmHg with the suit pressure below required, there is no protection afforded by the simulation model.

Where ΔP = Suit Pressure - Standard Pressure

For $\Delta P \leq -80$ Protection Value 0

For $-80 < \Delta P < 0$ $PV = \frac{42.8}{80} P = 42.8$

For $0 \leq \Delta P$ $PV = 42.8$

The G suit dynamic response characteristics are included in the simulation automatically as the G suit pressurization for the simulator pilot provides the driving signal to determine the protection value. Figure 3 is a block diagram representation of the G suit model.

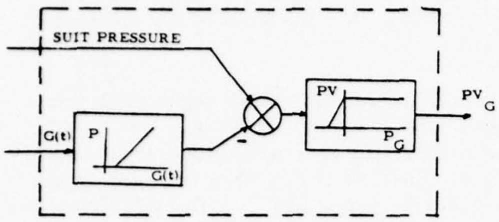

Figure 3. G Suit Model

THE STRAINING MODEL

Since the early days of flying, the value of muscular straining as protection against the effects of $+G_z$ acceleration have been recognized. Pilots observed that blackout or greyout could be postponed if they grunted or screamed and tensed the skeletal musculature during acceleration. The M-1 maneuver, defined as muscular straining with expiration against a partially closed glottis, is a most effective voluntary protection against the circulatory effects of $+G_z$ acceleration. The physiologic basis for this protection has been ascribed to its effect on increasing the arterial pressure at eye during acceleration. As forced expiration is instituted, the resulting increase in intrathoracic pressure is transmitted directly to the aorta and a like increase is felt at eye level.

Skeletal muscle is controlled by signals which are transmitted to selected motor units of a muscle through the motor neurons. The force generated by the muscle is the result of both the frequency of firing of motor units and the number of motor units which are recruited. The muscle tension is accompanied by electrical signals which can be detected by suitable electrodes on the skin surface. The electrical signal exhibits the characteristics of its primary source in that it represents a weighted sum of motor unit activations. There is, therefore, a correspondence between the EMG and muscle force.

The muscle straining maneuvers such as the M-1 and L-1 require a general tensing of skeletal muscle along with contraction of abdominal and peripheral muscles. The muscle straining is accompanied by the expiration of air through a partially closed glottis for the M-1. Both can cause increased intrathoracic pressure of 50 to 100 mmHg and consequently increase arterial blood pressure by a like amount.

This simulator model requires the presence of two signals to provide the maximum straining protection value, PVs. The signals represent the prime factors which are present in a properly executed straining maneuver. The EMG signal is generated by the straining subject and processed to provide and intermediate protection value PVm. The protection afforded by muscle straining is then modified by the timing of the straining maneuver.

The thoracic cavity is modelled as a flexible cylinder surrounded by a muscle girdle. The muscle straining signal representing muscle force around the thoracic volume is, therefore, assumed to bear a predictable relation to the internal pressure increase at low straining levels. At higher levels a maximum pressure is achieved and increases in muscles straining are no longer effective. The pressure straining relationship used in the model is a curve with a saturation level related to the maximum pressure rise in the thoracic cavity.

The effectiveness of the straining maneuver is also governed by the repetition rate. The straining protection value $K_2(t_r)$ is, therefore, modified by a function dependent upon maneuver repetition rate. Experimentally, $K_2(t_r)$ is maximum at 3-5 seconds according to Gillingham. Shorter time periods do not allow sufficient time for the internal pressure to rise and longer time periods involve countering responses due to baroreceptor feedback and reduced venous return to the heart. The generalized straining simulation block diagram is shown in Figure 4.

VISUAL LIMITS MODEL

The effect that acceleration has on the visual apparatus is observed in terms of tunnel vision, greyout, and blackout. During the periods when vision is impaired there are also decreases in visual activity; and

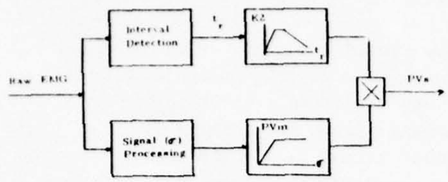

Figure 4. Straining Model

brightness contract detection ability. Although there are multiple factors related to the anatomy, psychology and physiology of the human which are responsible for these changes in visual perception, the structure of the eye is a primary factor and provides the basis for a useable model.

Consider the monocular field with the visual center located at the fovea, and the arterial supply offset and entering the retinal surface through the optic disk. The arterio lar branches which perfuse the retina spread out over the retina terminating in the capillaries, Figure 5. The major arterial

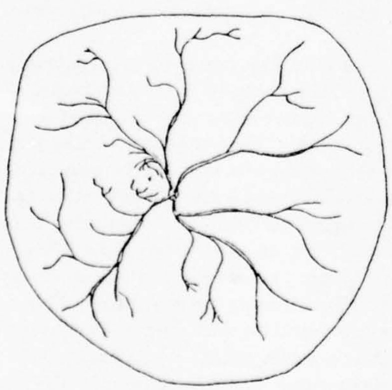

Figure 5. Retinal Artery Supply on Right Eye Field

branches course across the retina to form a general network which normally provides an adequate 0_2 blood supply to the retina. The arterial supply is formed so that a nominal pressure drop is encountered as the distance from the optic nerve entrance is increased, Figure 6.

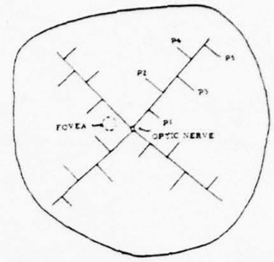

Figure 6. Linearized Representation of Blood to Retina

$P1 > P2 > P3 > P4 > P5$

When the pressure drops below a critical value, the more distal areas begin to feel the effects of blood and oxygen depletion. When the pressure at the retinal artery drops below the interocular pressure blood flow ceases and the retina is no longer capable of transmitting neural signals due to light detection in the rods and cones.

As an initial approximation the retinal supply network is assumed to be a linear network with the supply pressure distributed linearly across the network. That is at any point along the supply

$$\frac{dP}{dx} = K_i$$

Where dx is the distance along the arteriolar bed dP is the corresponding pressure change along dx and K_i is a function of the central supply. At some critical pressure blood flow ceases with the peripheral areas experiencing the initial blood flow shut off. The supply of blood and oxygen then decays inwardly toward the supply point and the visual sensitivity of the system decays in a like manner.

The visual field model can now be extended to a binocular field. Figure 7 is a binocular field map showing the coincident foveal areas as the visual center, and the optic disc for each eye in a manner that depicts the observed field from inside out. The outer lines depict the outer edges of the peripheral vision. Lowered blood pressure supply in each of the modeled retinas causes the field to collapse as concentric circles

with centers at each of the optic discs as shown by the dashed lines. Thus the visual field collapses toward a somewhat ellipsoidal shape with the vertical field having a smaller visual angle than the horizontal field.

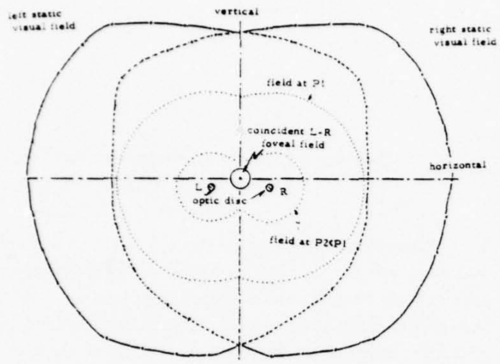

Figure 7. Binocular Visual Field Decay Due to Reduced Blood Supply Pressure

CONCLUSIONS AND RECOMMENDATIONS

The models presented in this study are designed for implementation in real-time simulation. As a consequence many simplifying assumptions have been made. The models do not represent the final stage of myoelectric integration but do provide a logical structure from which refinement can advance. There are gaps in the information available which must be filled to further refine the models and increase simulation fidelity.

Reevaluation of the visual model indicates that a dynamic model of the blood distribution system across the retina may be very valuable. A model analog can be seen in transmission line theory and could provide a single model for both peripheral and central visual fields.

A promising extension of the visual model would include a dynamic representation of oxygen transport at the synapse junctions in accordance with Miller and Green. Reduction of oxygen concentration levels due to impaired pulmonary function or exercise would play an important role in this extended model. The expected outcome would yield zonal gradients of contrast and acuity limits as a function of circulatory distance from the retinal supply. In the extended model both the available oxygen in the blood and the blood pressure would be important factors in defining the visual field response.

The extended model could provide definition of simulator display requirements by establishing maximum acuity and minimum brightness requirements for optimal scene projection fidelity based on visual capability. The extended model would also allow accurate manipulation of the generated scene in terms of both acuity, contrast and relative brightness.

Considerable benefit would result from an experimental procedure to determine the dynamic relationship between EMG and elevated blood pressure.

1) Experimental verification of the derived transfer function would provide the basis for refinement of the postulated model.

2) An evaluation of the energetic costs of the straining protective maneuvers could be derived from such a study and when incorporated into the current simulation model would provide a new method for evaluation of acceleration protection equipment.

Further exploration of electrode placement should include the possibility of using seat pan electrodes (recommended by K. Gillingham). This method would obviate the need for separate electrode preparation for each subject and provide the maximum in environmental fidelity. The simplifying assumptions used in linearizing the complex physiologic systems are both scientifically and pragmatically motivated. The reduction of assumption to fact for these models will require a wide range of experimental efforts. However, the system points in the new directions, provides the rationale and establishes the feasibility of biologic integration in training systems.

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MODIFICATION OF DEFENSE MAPPING AGENCY AEROSPACE CENTER (DMAAC) DIGITAL RADAR LANDMASS SIMULATOR (DRLMS) DATA BASE

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SUMMARY

A planar approximation for data compression of DRLMS data base is provided by General Electric. The data considered were the terrain elevation slope between adjacent points within a 1° X 1° rectangle. Because of the heterogeneity such a large area, smaller areas 1/1600 of the 1° X 1° rectangle were considered and the planar approximation applied to each of the smaller rectangles. To substantiate the need for a reduction of the 1° X 1° area, a roughness index for each of the 1600 blocks in the area in question was calculated.

The Grumman modification of the General Electric "Trig" (Triangle Generation) algorithm which implements this planar approximation reduces computational time and enhances the fidelity of the simulated video signal.

DISCUSSION

The Digital Radar Landmass Simulator (DRLMS) simulates the ground mapping of all modes of the AN/APQ-156 Radar. It is required that this simulator be realistic enough to the ground training environment to permit substitution of simulator time for flight training time. A combined effort of General Electric and Defense Mapping Agency Aerospace Center (DMAAC) produced a system, currently incorporated in A6E-WST, in which DRLMS computes radar video signals for each resolvable element of the earth's surface illuminated by the radar antenna. The DMAAC off-line digital data base contains terrain relief data that was digitized as the elevation values at the intersections of a grid and also the cultural descriptive data that likewise was digitized onto a grid. Stored terrain and cultural data from the DMAAC data base is used for computing the radar receiver output and this information is used to drive the radar display. It is specifically the terrain file to which this report addresses itself. The DRLMS employs three range dependent on-line data bases to simulate radar images; these are:

- o Long Range (75 n. mi. - 150 n. mi.)
- o Medium Range (27.5 n. mi. - 75 n. mi.)
- o Short Range (5 n. mi. - 27.5 n. mi.)

To generate the data base for the DRLMS, the grid terrain model is defined by DMAAC and a planar approximation, used for data compression, is provided by GE. The planar technique for terrain modeling is a variable compression method -- planar segments being very large in areas where the world is flat and such segments being small where the terrain is rugged. With this variation, such an approach should allow placement of the data where it is needed.

A. General Electric Basic Trip Algorithm

The planar approximation, implemented in G.E.'s "Trig" (Triangle Generation) Algorithm, adjusts range dependent parameters not only to satisfy the overall terrain elevation but also to be self-adaptive to the memory system capacity. A major disadvantage of this technique is that the parameters are only range dependent and not terrain quality dependent. It is to rectify this insufficiency that the Grumman modification was initiated.

A typical GE selected data base represented 1.6 X 10^6 square miles, or 1600 31 element X 31 element arrays. The actual terrain elevation for each array position (DMAAC) is compared with the elevation on the plane (GE derived) for the same X-Y location, and the absolute value of this difference is calculated. Then, the mean deviation of these differences is computed. If the absolute difference of any X-Y location exceeds some input parameter, α, or if the mean deviation of the planes exceeds the input parameter, ε, the model is rejected, and a new model is constructed. While the (α, ε) parameters were selected for 31x31 blocks, 1600 such blocks representing a one by one degree area, were compiled and

investigated in their entirety. Only one parameter set applied to the block conglomerate. Such a philosophy is adequate if the terrain of these 1600 blocks is homogeneous. For areas of heterogeneity, however, the data compression technique produces a compromised data base that does not meet the subjective requirements for smooth areas within the heterogeneous area.

If the original 31x31 word array is rejected, a new model is formed by dividing the 31x31 array into four 16x16 subarrays with two planes for each.

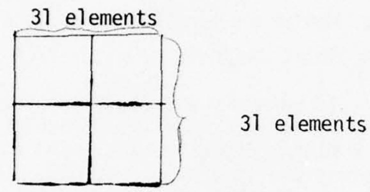

Figure 1: 16x16 subarrays

Again, each of the 16x16 element subarrays is investigated to determine its passing the α, ε criterion. If failure exists, each subarray is further subdivided and again tested. If less than three of the quadrants fails, the array is subdivided into nine mini-arrays (Fig. 2) and then twenty-five mini-arrays (Fig. 3). If, then, any of the twenty-five mini-arrays fail the tests, the entire subarray structure is abandoned as it would have been if three or four of the subarrays shown in Figure 2 had failed.

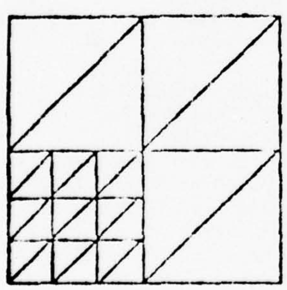

Figure 2: Nine Mini-Arrays

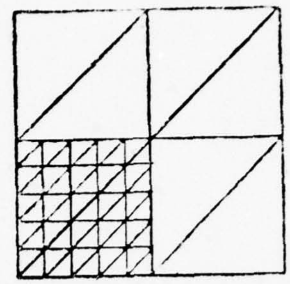

Figure 3: 25 Mini-Arrays

At this point the basic 31x31 array would be divided into nine subarrays each with two planes defined by its corners and diagonal as shown in Figure 4.

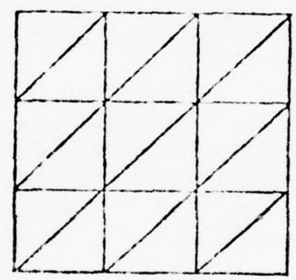

Figure 4: Nine Subarrays

Further subdivisions are illustrated in Figures 5 and 6.

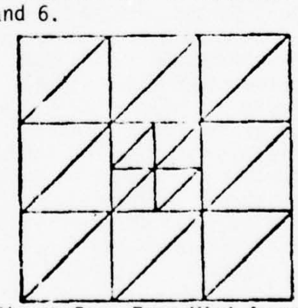

Figure 5: Four Mini-Arrays

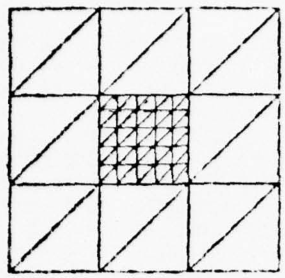

Figure 6: 25 Mini-Arrays

The subdivisions are evident but the conditions for these subdivisions should be stated. If less than five of subarrays fail, further subdivision is performed as in Figure 5. If any of the planes defined by the four mini-arrays of Figure 5 occurs the subarray is replaced by 25 mini-arrays as in Figure 6. No further reduction occurs. If more than five of the nine subarrays of Figure 4 occurs, the basic 31x31 array is configured into 25 subarrays as in Figure 7. If, then, any subarray fails it is replaced by four mini-arrays as in the left center of Figure 8. If any mini-array fails the test, the four mini-arrays will be replaced by nine mini-arrays as shown at right center of Figure 8. No additional reduction will occur.

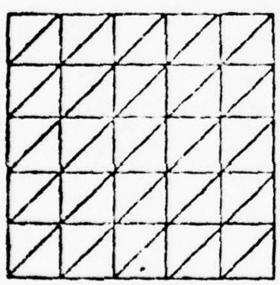

Figure 7: 25 Subarrays

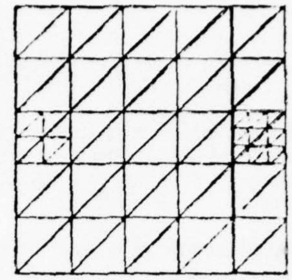

Figure 8: 25 Subarrays with 4 and 9 Mini-Arrays

Needless to say, such data manipulation is time consuming with apparently little statistical rigor. Grumman proposed to modify the GE "Trig" Algorithm by incorporating the Air Force roughness index equation. Considering roughness, or terrain characteristics, of each 31x31 word array, an α, ε can be assigned to each block of 961 elements.

B. Grumman Modification of Trig Algorithm

To accommodate terrain heterogenity within a $1^{\circ} \times 1^{\circ}$ block, the roughness equation proposed by the Air Force for the DRLMS requirements for the B1 was incorporated and proposed as a patch to the existent software routine. This equation will be used so that the selection of α, ε for the TRIGEN routine may be optimized. A statement of the equation, appears in Specification CP001-07878-139A dated 3 September 1976. From work done with DMAAC, probable ranges of α, ε for the variable α, ε study were proposed.

1. Air Force Roughness Equation Statement

Roughness index is a measure of terrain variation and the equation for calculation is:

(1)

$$R = \frac{1}{(n-2)^2} \sum_{i=2}^{n-1} \sum_{j=2}^{n-1} \frac{\{|2e_{i,j} - e_{i,j+1} + e_{i,j-1}| K + |2e_{i,j} - e_{i+1,j} + e_{i-1,j}|\}}{4}$$

where n = 31

R = Terrain Roughness (Elevation Variation) Index

$e_{i,j}$ = element of an nxn terrain elevation matrix whose elements are spaced in equal increments of latitude and longitude.

$e_{1,1}$ = elevation of SW corner of matrix (meters)

$e_{n,1}$ = elevation of NW corner of matrix (meters)

$e_{1,n}$ = elevation of SE corner of matrix (meters)

$e_{n,n}$ = elevation of NE corner of matrix (meters)

K = meridian convergence term for entire matrix

$$K = \left[\frac{\cos\ (\text{latitude of } n^{th} \text{ row})}{(2)\ \ (Z)} + \frac{\cos\ (\text{latitude of first row})}{(2)\ \ (Z)}\right]^{-1} \qquad (2)$$

where Z = 1 for latitudes $\leq |50|$
= 1/2 for latitudes $|50\text{-}70|$
= 1/3 for latitudes $|70\text{-}75|$
= 1/4 for latitudes $|75\text{-}80|$
= 1/6 for latitudes $|80\text{-}90|$

2. Interpretation of Roughness Equation

A. Roughness Equation

In a 31x 31 block, the elevation of all the points except the corner points are considered. For each j (point along the y axis), keeping i constant, the sum of the elevations of the (j+1) st and the (j-1) st terms is subtracted from 2 times the j^{th} point.

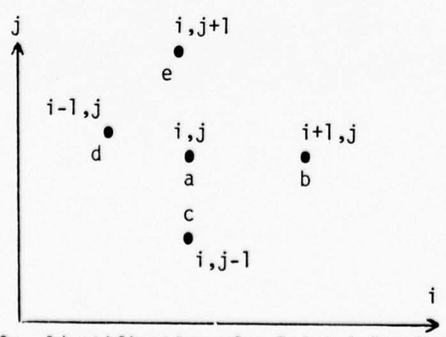

Fig.9: Identification of a Point & Its Neighbors

For example, consider the point i, j-

In reading equation (1), we first sum according to j. Multiply the the elevation of the point a by 2 and subtract from it the sum of the elevations of points e and c. The absolute value of this difference is then multiplied by a meridian convergence factor (see eq. 2) and added to an elevation term in which j is kept constant. This term is formed by multiplying point a by 2 and subtracting from it the sum of the elevations of b and d. Once all the points with constant i are considered, i is advanced to the next integer and a similar computation is effected, the result of which is added to the previous composite sum. There will be $(n-2)^2$ such calculations comprising the roughness index calculation. The meridian convergence term (k) is introduced to standardize the distance between consecutive readings.

B. Interpretation

The salient points that the roughness index will quantify for each area of topography subjected to the test, are the degree and direction that the slope between two points is changing. For example, the western desert areas, with a constant grade covering large areas, will exhibit a RI of zero the same as if it were a body of water. In a similar manner, those western areas in which the terrain has dramatic changes due to crests and ridge hills exhibit a significantly high RI. (Test results indicate a value of 10.9 for 48/121 region). Basically the RI is a point-to-point measurement of the change rate in slope between adjacent data points.

Roughness index will assume only positive values. A roughness index of 0 indicates that the elevation slope from the central point to each of its neighbors is zero, or constant in magnitude and direction. A roughness index greater than zero indicates the slope changes from the central point to each of its neighboring points. Let us assume that the points a,b,c,d and e (Figure 9) all have equal elevations (EL1), then each term of the summation will be 2(EL1)-(EL1+EL1) or zero. Again, referring to Figure 9 if the (elevation of point a - elevation of point b) =- (elevation of point a - elevation of point d), and (elevation of point a - elevation of point e) =- (elevation of point a - elevation of point c), the roughness index calculates to be zero. To illustrate, consider point a_1 of the contour map.

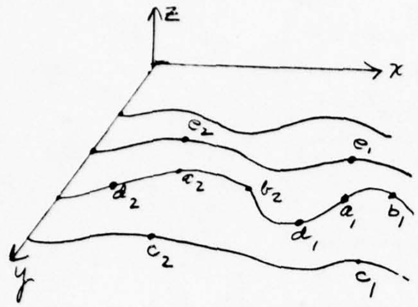

Figure 10: Contour Map Illustrating Roughness

Although points $b_1 c_1 d_1 e_1$ are not equal in elevation to a_1, the slope of the terrain around it is constant. Therefore, point a_1 is the average of the elevation of its equally distant neighbors b_1 & d_1; as well as c_1 and e_1. This point thereby adds zero to the roughness calculation for the area.

On the other hand point a_2 is at the peak of a hill, and is not the average elevation of its neighbors b_2,c_2,d_2 and e_2; thereby, making a positive contribution to the roughness calculation. Since absolute values are used in the calculations, a depression of equal magnitude to the peak at point a_2 would contribute an equal amount to the roughness calculation.

Regardless of range, the sample size for roughness calculation will be (n-2) where n = 31. For short range at latitude of 40° there is an interval of 200 feet in longitude and 300 feet in latitude between points, in medium range a difference of 1000 feet in longitude and 1500 feet in latitude between points, and in long range a difference of 2000 feet in longitude and 3000 feet latitude.

3. Results of Roughness Index Calculation

Figures 11-16 inclusively, illustrate the results of the roughness index calculation for 1.5x1.5 min. blocks in areas of latitude, longitude combinations of 34/77, 36/77, 47/120, 47/121, 48/120, 48/121, respectively. East coast terrain is relatively flat in comparison to that of the west coast Reference to maps for each of the specified areas will illustrate the fidelity of the roughness indices to the actual terrain roughness. Each of the Figures 4-10 represents a $1^\circ \times 1^\circ$ block at short range. The specified location is that of the Southwest corner of the area under consideration.

Typical roughness maps can be used to establish an α, ε for each 31x31 word array (1.5x1.5) min. This will serve several purposes among which will be the reduction of time necessary to form subarrays, when statistical variation within a block is pronounced and also a computational time reduction for recalculation when the memory system capacity is exceeded.

This effort justified the need for modifying the GE "Trig" Algorithm.

******************* U N C L A S S I F I E D ******************* DATE 120677 PAGE 24

*** START TERRAIN EXTRACT ***

PHASE I STARTS AT 012444 ON 120677

*** NAMELIST CARDIN -- RANGE = 1, ICOUNT = 7584
THIS TAPE FROM ZONE 1

***10X ROUGHNESS INDEX FOR 1.5 X 1.5 MIN BLOCK ** *

1	1	0	0	0	0	1	2	1	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	1	1	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
0	0	2	2	2	1	1	1	0	0	0	0	0	0	0	1	1	0	0	1	1	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	2	1	1	2	1	1	0	1	0	0	0	1	0	0	0	0	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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*** THE AVERAGE ROUGHNESS FOR THE 1 X 1 DEG IS .02.

PHASE I ENDS AT 020407 ON 120677

****

* SUPS THIS RUN: TOTAL = 658.345 CPU = 128.103 I/O = 530.242 (INCLUDES CC/ER)

****

@ADD,P TERRAIN-D

@FREE 1.

@FREE 4.

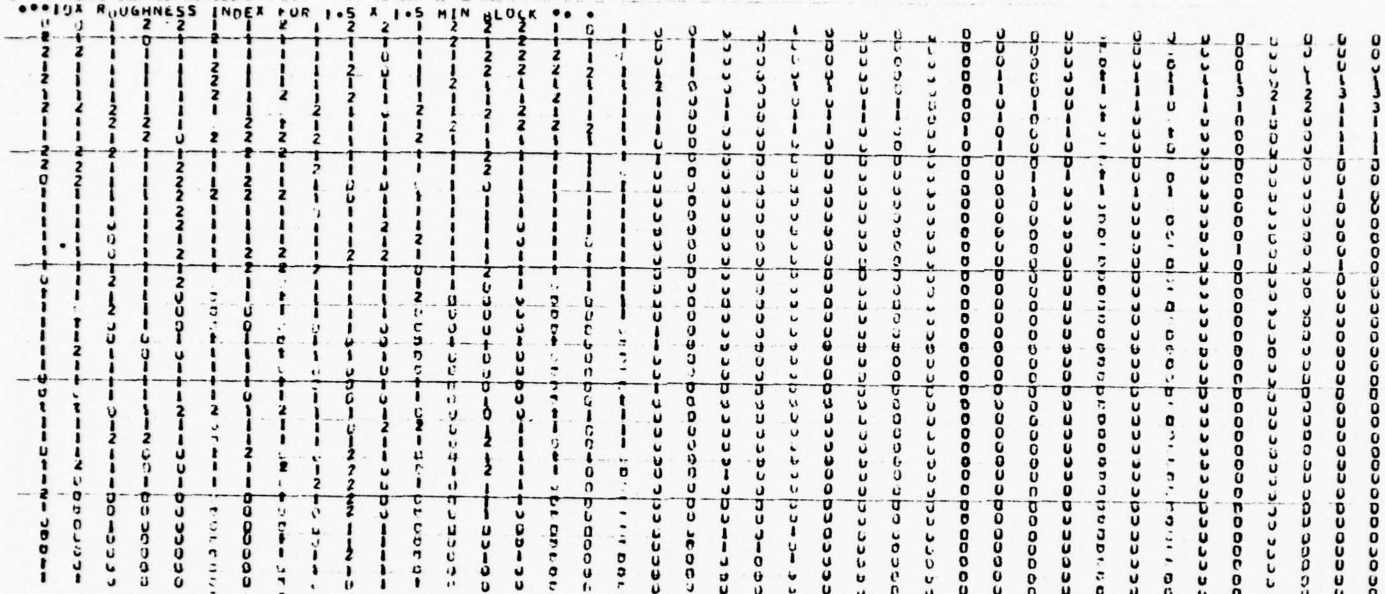
@XQT T-TRIANGLES

ROUGHNESS INDEX MAP FOR 34°N LAT, 77°W LONG

FIGURE 11

```
****************** U N C L A S S I F I E D ******************          DATE 120877          PAGE    24
*** START TERRAIN EXTRACT ***
**PHASE 1 STARTS AT 1U14IR ON 120877**
*** NAMELIST CARDIN -- RANGE = 1,  ICOUNT = 50000
THIS TAPE FROM ZONE   1

***10X ROUGHNESS INDEX FOR 1.5 X 1.5 MIN BLOCK ** *
```



```
*** THE AVERAGE ROUGHNESS FOR THE 1 X 1 DEG  IS  .08
**PHASE 1  ENDS  AT 103802 ON 120877**
************************************************************************
* SUPS THIS RUN:  TOTAL = 659.167          CPU = 129.574          I/O = 529.693 (INCLUDES CC/ER)
************************************************************************

@ADD,P   TERRAIN-D
@FREE    1.
@FREE    4.
@XQT     T-TRIANGLES
```

ROUGHNESS INDEX MAP FOR 36°N LAT, 77°W LONG

FIGURE 12

•••••••••••••••••••• U N C L A S S I F I E D •••••••••••••••••••• DATE 1-0777 PAGE 24

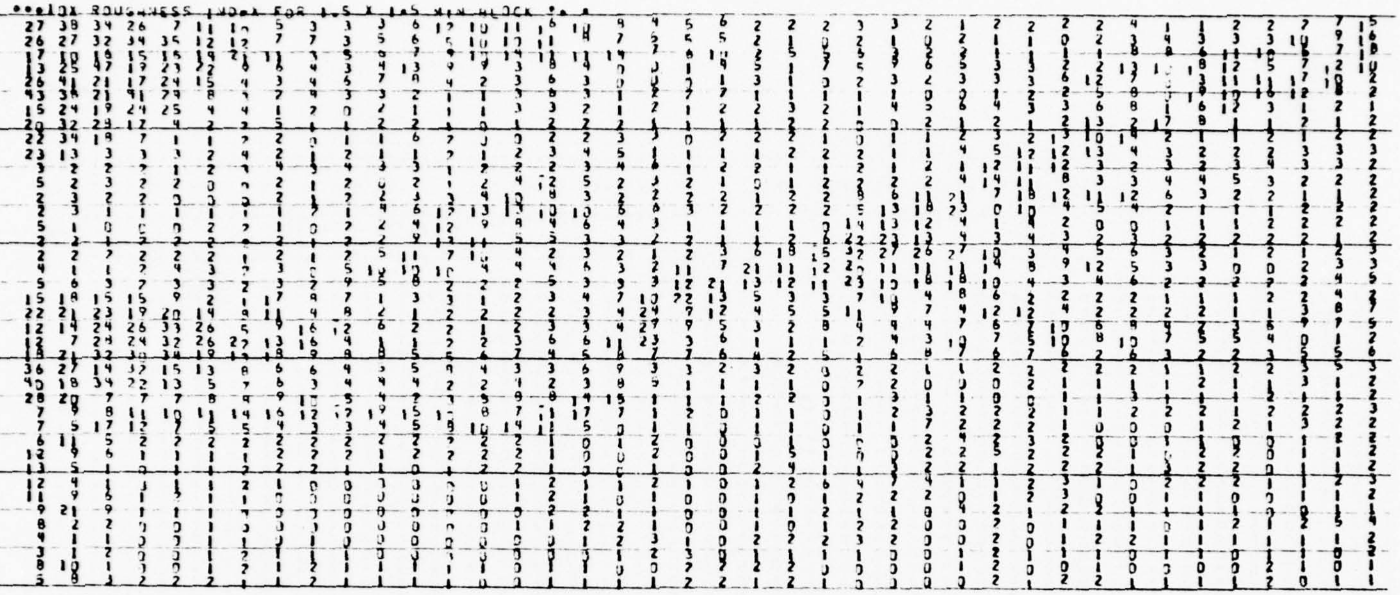
••• START TERRAIN EXTRACT •••

••PHASE I STARTS AT 075936 ON 120777••

••• NAMELIST CARDIN -- RANGE = 1, ICOUNT = 8948

THIS TAPE FROM ZONE 1

•••IDX ROUGHNESS INDEX FOR 1.5 X 1.5 MIN BLOCK •• •



••• THE AVERAGE ROUGHNESS FOR THE 1 X 1 DEG IS .53•

••PHASE I ENDS AT 072429 ON 120777••

• SUPS THIS RUN: TOTAL = 655.248 CPU = 134.693 I/O = 522.555 (INCLUDES CC/ER)

#ADD,P TERRAIN-D

#FREE 1.

#FREE 4.

#XQT T-TRIANGLES

ROUGHNESS INDEX MAP FOR 47°N LAT, 120°W LONG

FIGURE 13

*** START TERRAIN EXTRACT ***

PHASE I STARTS AT 062040 ON 120877

*** NAMELIST CARDIN -- RANGE = 1, ICOUNT = 13164
THIS TAPE FROM ZONE 1

***10X ROUGHNESS INDEX FOR 1.5 X 1.5 MIN BLOCK ** *

36	31	48	46	50	42	52	23	37	49	40	42	42	34	44	42	23	24	30	28	25	16	33	30	37	43	34	42	23	17	22	9	23	30	34	34	31	31	33	26
44	43	30	37	47	53	48	41	15	33	27	41	37	23	34	35	41	23	23	33	31	20	25	33	43	50	50	36	29	33	34	20	10	21	24	21	34	25	22	21
45	50	27	25	46	41	57	35	37	15	25	26	45	39	20	36	49	36	36	35	39	40	33	35	32	33	44	50	42	37	35	15	8	16	27	23	17	16	22	14
41	43	33	25	25	27	15	35	43	24	9	15	36	45	12	20	25	33	36	34	45	36	35	35	44	22	47	32	34	33	41	15	5	9	19	20	13	16	23	5
40	40	40	25	19	26	40	[illegible]	[illegible]	30	25	13	21	39	37	25	26	23	34	51	53	38	25	46	50	45	34	41	50	37	31	21	1	5	3	9	12	11	20	16
16	1	23	29	27	15	26	43	34	13	23	17	10	18	27	16	20	20	37	34	33	50	41	40	41	40	49	40	44	43	34	23	20	25	6	2	6	9	18	16
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41	40	52	52	47	36	53	26	43	52	34	29	48	38	36	55	37	38	34	39	33	38	51	36	37	48	48	31	39	21	31	20	35	36	3	2	1	2	7	2
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33	36	20	22	23	17	14	31	40	26	26	42	38	32	19	16	18	23	19	25	36	46	26	26	37	25	43	15	26	19	15	28	39	27	25	21	7	15	25	34
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23	12	14	5	3	10	17	17	39	37	33	41	39	44	39	24	23	11	19	18	14	16	28	17	14	15	10	19	26	28	30	26	20	33	38	37	9	22	9	7
11	20	24	22	26	13	12	9	25	44	38	31	27	36	34	24	14	6	9	16	17	10	13	18	17	10	11	10	20	27	28	39	18	32	45	49	18	16	19	12
3	11	15	13	11	9	7	7	10	10	10	20	32	34	25	20	21	12	12	11	19	16	16	17	14	16	9	3	6	15	26	29	36	44	45	50	31	17	7	3
2	1	3	4	3	2	4	5	16	13	5	12	20	21	17	20	24	11	15	22	10	23	29	15	26	12	25	18	10	4	18	36	36	50	43	46	38	30	23	8
6	13	11	16	5	11	7	6	13	13	28	15	13	10	6	9	18	25	18	24	11	26	23	13	25	16	37	25	7	10	29	24	56	44	50	32	18	11	12	21
22	17	17	20	23	15	17	9	11	12	15	6	5	10	3	3	3	9	13	17	20	30	19	17	24	24	22	13	26	21	34	33	33	45	28	25	35	35	25	15
30	32	30	20	19	24	26	15	7	3	7	6	12	3	3	3	3	3	4	3	3	5	9	16	20	13	22	30	29	26	14	47	53	33	44	49	44	30	38	10
29	37	17	14	24	28	20	32	27	21	6	1	1	8	3	1	2	3	3	2	2	2	4	9	8	5	10	24	30	22	19	34	43	33	33	28	18	28	17	9
25	16	14	16	5	7	16	15	29	24	13	4	0	9	22	9	4	9	6	3	3	3	4	3	7	5	4	14	26	39	21	34	45	36	30	21	14	21	14	9
13	6	18	13	22	20	25	18	28	20	21	11	3	3	1	7	4	7	3	3	3	4	3	3	2	5	[illegible]	10	28	29	16	7	21	35	36	23	21	21	23	13
10	10	15	21	20	18	2	25	10	20	23	22	7	4	3	2	2	2	2	2	2	3	3	3	2	2	3	9	14	16	17	15	24	25	22	19	10	13	9	12

*** THE AVERAGE ROUGHNESS FOR THE 1 X 1 DEG IS 2.74.

PHASE I ENDS AT 063412 ON 120877

****

* SUPS THIS RUN: TOTAL - 659.776 CPU = 123.110 I/O = 536.666 (INCLUDES CC/ER)

****

@ADD,F TERRAIN-D

@FREE 1.

@FREE 4.

@XQT T-TRIANGLES

ROUGHNESS INDEX MAP FOR 47°N LAT, 121°W LONG

FIGURE 14

****************** U N C L A S S I F I E D ******************   DATE 120577   PAGE 24

*** START TERRAIN EXTRACT ***

PHASE I STARTS AT 175733 ON 120577

*** NAMELIST CARDIN -- RANGE = 1, ICOUNT = 1173C
THIS TAPE FROM ZONE 1

***10X ROUGHNESS INDEX FOR 1.5 x 1.5 MIN BLOCK ** *

15	23	23	31	26	23	25	17	25	39	44	5	30	9	14	19	21	20	12	19	23	12	1	16	13	12	20	16	10	5	7	10	15	17	12	9	8	16	19	13
24	16	22	22	33	34	14	22	32	39	36	8	24	21	23	19	18	16	20	24	19	17	3	10	11	9	9	11	8	5	8	16	10	9	10	8	12	13	11	32
27	26	15	12	24	19	11	13	12	28	62	27	13	12	24	21	16	13	15	16	21	14	4	5	14	12	12	19	9	10	7	6	7	12	13	7	8	9	18	30
22	24	15	12	15	19	14	12	15	20	17	18	29	13	17	22	18	22	13	12	7	18	2	24	22	21	16	8	11	6	7	9	11	9	10	7	14	9	12	19
12	17	11	14	13	16	11	14	15	19	25	15	17	27	29	5	21	17	15	12	18	16	2	15	15	18	13	16	12	12	8	14	13	5	9	7	8	10	9	23
18	20	19	12	20	13	16	14	23	21	19	21	18	16	13	26	20	9	14	14	15	13	8	2	15	13	12	9	18	15	9	16	15	14	12	5	11	11	7	26
29	24	23	23	17	15	19	22	27	27	19	24	25	13	16	17	10	10	13	10	11	14	10	0	12	11	10	5	7	7	5	7	5	12	10	10	12	14	10	16
27	21	24	27	29	20	16	14	16	21	23	23	26	25	21	22	16	13	12	5	9	12	11	3	18	10	15	13	17	3	6	4	7	9	11	9	14	15	13	10
17	18	21	22	20	18	14	17	25	20	16	24	19	19	19	20	7	7	8	6	5	13	8	2	22	9	17	17	5	17	18	19	10	10	17	21	13	12	13	12
16	8	21	19	17	21	25	19	21	19	25	27	21	18	18	23	6	8	10	13	14	16	9	2	13	10	10	10	3	6	9	12	13	14	17	10	8	11	5	5
23	12	13	20	23	24	23	23	26	23	18	26	25	14	26	20	19	4	3	6	10	14	24	9	14	4	5	8	8	9	10	17	21	11	18	12	9	7	8	10
15	14	14	16	24	33	33	37	29	23	17	18	18	22	15	16	16	9	5	5	7	5	6	6	10	8	10	11	7	10	14	21	15	17	10	11	16	9	4	10
11	13	22	37	19	25	35	37	29	12	30	35	21	25	11	15	22	14	8	4	5	5	10	15	13	13	13	15	11	13	17	9	17	18	11	11	10	10	6	14
20	19	24	36	35	19	16	24	31	14	13	22	24	14	9	15	15	13	14	14	12	7	25	15	10	14	7	10	10	16	9	12	6	7	15	17	17	21	16	15
21	24	30	34	32	28	26	21	26	17	10	22	21	15	9	16	16	20	13	15	9	10	16	10	9	14	10	11	9	13	11	13	12	6	7	8	11	13	8	11
27	23	28	27	30	33	25	31	20	26	20	25	23	25	10	11	17	14	16	9	11	21	10	15	8	8	6	9	12	21	10	9	15	10	6	8	8	7	8	13
22	32	27	26	16	15	12	25	25	23	27	30	37	22	12	13	14	10	[illegible]	8	14	13	10	13	14	17	13	11	7	12	[illegible]	7	11	10	12	9	9	10	17	12
14	19	27	20	12	12	14	14	20	19	22	21	21	21	17	16	6	20	6	10	13	16	8	7	4	5	7	11	14	16	16	13	12	15	11	10	19	21	14	14
23	20	32	19	15	15	15	19	13	22	21	12	12	17	15	17	7	14	12	13	11	15	23	11	8	4	4	4	12	17	10	14	13	9	8	10	14	11	21	8
21	21	22	24	25	26	10	13	13	22	31	20	11	8	11	10	14	11	15	5	24	8	13	15	10	9	5	4	3	6	10	19	19	16	20	19	17	18	10	7
24	24	20	21	20	30	26	13	16	22	25	25	11	8	13	10	10	5	3	5	9	22	13	16	14	15	14	10	4	5	14	5	10	10	15	19	16	9	7	9
28	26	17	23	18	30	16	22	16	17	23	21	22	13	14	13	11	8	2	2	4	9	18	15	13	14	17	17	17	18	18	9	16	11	13	17	11	14	4	9
40	33	23	14	21	24	25	22	20	23	27	14	23	18	21	16	17	2	2	6	2	4	10	11	8	10	14	22	13	16	19	19	15	12	9	4	10	11	10	14
30	25	22	18	21	16	16	17	23	19	21	17	22	13	22	19	12	4	3	3	5	6	9	7	7	14	19	15	7	7	13	14	15	17	8	1	3	13	25	19
29	29	29	16	12	16	9	9	11	21	[illegible]	14	22	15	19	11	9	7	3	4	5	5	11	12	9	4	6	8	11	11	6	7	8	13	16	13	14	20	16	15
28	29	22	16	9	14	18	17	15	16	20	12	14	23	19	9	5	7	7	11	6	17	16	17	15	11	6	4	8	7	5	5	6	12	11	19	14	22	18	17
31	24	21	11	11	8	8	6	17	18	26	15	10	19	7	6	10	7	12	12	16	19	17	28	17	10	5	3	5	4	10	6	8	8	14	22	20	20	21	20
19	28	19	21	17	12	7	4	8	21	19	14	6	4	7	7	9	8	6	7	6	16	14	14	20	15	16	11	16	11	17	13	5	6	5	8	12	16	12	22
21	14	19	14	7	13	9	5	12	6	17	8	8	15	12	9	9	3	6	5	4	6	22	8	12	13	12	9	10	13	13	12	8	15	9	6	21	15	16	13
21	20	19	9	8	13	13	16	15	18	11	7	12	13	11	9	7	1	1	2	1	1	5	13	7	8	14	13	10	6	18	10	11	16	18	19	18	14	23	11
20	9	6	12	9	11	17	12	16	13	10	5	14	9	6	10	5	4	4	3	3	2	0	6	8	4	8	12	10	14	9	13	16	10	14	9	11	12	13	12
17	11	11	10	6	9	7	17	14	9	12	4	9	12	6	9	7	3	2	3	0	2	1	4	9	4	10	16	5	6	10	9	11	7	10	4	6	14	12	7
21	14	15	[illegible]	7	8	6	15	9	17	9	5	5	4	4	6	2	2	1	4	1	1	1	2	8	3	6	16	16	20	16	20	15	10	14	12	19	13	14	9
18	14	15	20	14	10	12	20	12	5	10	1	3	7	7	7	6	3	2	3	1	1	3	5	7	6	4	14	10	11	16	10	17	16	22	22	18	21	20	16
12	15	19	17	10	13	18	9	15	5	5	3	6	7	5	7	4	1	1	2	9	5	4	5	5	9	8	4	13	9	10	6	14	12	15	21	17	17	14	16
13	17	14	9	11	9	17	17	15	5	3	4	2	4	4	10	4	1	1	3	8	6	6	4	2	3	11	10	5	7	10	7	5	9	17	13	11	9	11	10
16	13	16	10	11	14	12	6	15	15	4	1	1	7	4	8	3	5	9	15	13	11	9	4	3	7	8	9	11	13	5	10	11	8	13	8	5	8	13	10
24	14	13	13	3	10	9	8	9	11	18	15	2	5	6	5	7	4	8	12	7	16	13	11	13	10	8	9	10	3	0	11	8	3	3	2	1	7	10	12
30	20	12	7	8	13	9	3	6	3	7	12	7	7	7	6	7	8	8	4	4	2	5	9	11	12	15	14	6	2	2	3	6	6	3	2	5	10	8	11
25	32	23	3	2	14	9	7	2	2	6	6	9	7	8	8	10	9	4	1	2	3	4	2	2	1	2	2	2	2	2	2	2	2	4	2	3	8	10	6

*** THE AVERAGE ROUGHNESS FOR THE 1 x 1 DEG IS 1.38.

PHASE I ENDS AT 181456 ON 120577

* SUPS THIS RUN: TOTAL = 660.666 CPU = 129.959 I/O = 530.707 (INCLUDES CC/EF)

@ADD,P TERRAIN-D

@FREE 1.

@FREE 4.

@XQT T-TRIANGLES

ROUGHNESS INDEX MAP FOR 48°N LAT. 120°W LONG

FIGURE 15

THIS PAGE IS BEST QUALITY PRACTICABLE
FROM COPY FURNISHED TO DDC

****************** U N C L A S S I F I E D ****************** DATE 120877 PAGE 25

*** START TERRAIN EXTRACT ***

PHASE 1 STARTS AT 022134 ON 120877

*** NAMELIST CARDIN -- RANGE = 1, ICOUNT = 14404
THIS TAPE FROM ZONE 1

***10X ROUGHNESS INDEX FOR 1.5 X 1.5 MIN BLOCK ** *

62	61	47	55	67	64	56	23	34	46	39	32	34	26	28	31	31	23	28	25	26	29	30	32	27	23	26	20	9	24	18	26	45	32	38	37	20	27	30	20
57	53	46	53	57	48	31	39	35	42	26	36	39	20	35	28	19	24	32	27	32	28	27	27	28	34	37	22	19	23	12	8	26	20	36	18	13	20	23	20
31	50	43	52	44	44	51	47	36	36	25	25	31	34	39	11	15	30	33	35	43	41	46	38	28	36	39	20	34	26	31	24	32	29	29	25	16	18	31	14
23	53	49	47	46	49	62	47	41	36	31	43	43	43	17	7	28	24	25	32	32	37	33	37	36	36	34	23	25	29	33	19	36	33	28	28	19	23	14	18
44	50	52	51	53	53	56	51	43	43	29	30	34	75	7	20	37	43	30	41	35	35	47	35	33	38	36	40	37	44	31	34	29	23	23	27	25	23	24	21
55	45	47	49	49	55	36	32	39	47	40	36	31	19	36	30	44	31	49	37	31	37	40	42	47	43	33	31	30	41	29	34	37	33	26	23	37	20	36	35
47	45	37	45	43	35	41	37	25	39	34	20	17	32	35	17	45	53	47	36	34	35	42	35	39	41	41	34	32	37	34	31	36	32	27	24	27	20	39	35
73	46	39	35	40	34	39	29	26	37	32	16	32	34	35	29	45	39	47	36	32	42	49	55	30	41	38	33	34	34	41	46	36	36	34	31	35	23	38	40
55	60	63	34	49	44	41	50	38	44	39	25	22	42	24	37	41	42	47	43	31	29	45	46	53	40	48	42	33	35	32	40	50	30	30	34	43	39	36	23
62	56	45	50	33	33	54	65	51	35	35	37	24	27	25	48	37	46	57	43	36	41	44	49	47	55	63	41	31	26	36	33	32	30	19	40	39	35	23	18
47	43	39	52	29	39	54	52	37	37	52	41	35	31	26	46	47	53	42	52	36	62	65	67	51	41	43	57	28	27	25	36	38	34	19	41	37	26	22	24
40	32	56	56	77	46	49	55	33	33	32	36	32	23	27	36	47	51	46	48	42	62	48	41	47	40	36	38	27	26	17	32	30	22	22	23	36	34	39	27
56	42	46	41	40	50	41	47	44	61	31	36	37	46	36	36	37	50	46	40	37	27	41	37	31	38	29	28	22	18	23	20	26	24	19	33	38	39	32	21
55	46	40	44	43	40	45	45	37	43	41	44	39	57	60	54	43	34	30	27	23	27	19	29	22	25	33	32	32	28	20	26	19	21	19	31	25	27	34	19
37	53	63	45	47	29	32	43	29	34	40	55	53	47	53	61	59	36	28	23	18	39	26	36	34	34	34	27	35	34	19	16	22	21	21	26	27	32	29	23
37	43	54	51	43	44	25	28	40	25	68	43	39	56	49	40	43	45	36	32	29	17	24	25	26	32	38	32	25	27	24	28	21	21	27	32	27	31	30	35
37	42	47	51	58	57	50	28	23	55	43	51	43	43	36	30	47	44	31	24	26	21	27	15	13	25	24	34	32	22	19	20	17	19	32	33	38	36	29	20
43	54	73	44	52	61	56	50	27	31	48	41	41	40	37	41	51	37	37	40	37	34	30	39	28	12	17	24	19	19	23	21	14	26	26	36	31	33	35	19
42	43	40	46	50	53	50	74	70	26	48	41	41	38	46	51	68	47	36	57	53	42	34	30	28	41	9	17	21	23	22	18	10	26	21	27	36	34	30	21
31	37	42	53	71	44	61	51	51	51	44	43	39	59	63	54	42	48	49	43	49	48	45	36	38	36	36	29	7	7	13	16	4	11	16	30	34	35	29	21
50	43	40	73	50	38	31	44	50	46	46	41	44	60	57	58	75	45	46	52	31	43	38	44	35	35	37	31	24	15	6	5	4	12	6	18	28	34	27	29
56	70	46	38	68	61	37	48	49	35	45	33	42	49	53	64	51	36	53	51	42	44	39	41	42	33	41	38	28	20	14	9	3	9	16	22	19	29	32	27
77	65	52	36	39	22	57	51	50	23	45	49	38	36	53	59	62	45	26	25	39	47	48	43	39	32	33	33	33	19	16	15	8	5	13	21	22	18	20	37
60	87	59	45	45	32	39	56	73	59	62	46	47	43	33	42	50	47	45	39	19	33	38	40	41	30	25	31	28	24	33	31	18	6	4	25	17	23	21	38
55	58	48	48	58	48	28	44	56	56	56	46	42	34	51	53	64	68	39	49	40	27	18	29	35	38	31	13	20	21	25	17	19	18	7	15	24	15	13	16
37	41	63	40	28	30	42	46	50	37	26	52	49	48	42	43	47	40	47	44	50	49	45	20	16	20	20	24	31	29	26	25	25	23	21	10	9	11	10	15
40	58	42	33	35	57	50	39	45	52	50	21	21	52	63	36	36	29	40	33	48	45	40	42	33	36	29	27	23	36	30	32	34	26	36	35	13	3	8	20
44	63	55	26	79	69	52	44	41	51	70	75	50	15	44	69	42	33	33	33	35	45	42	43	33	32	27	25	22	30	33	35	35	32	42	33	20	3	19	25
44	55	35	53	51	56	43	49	40	56	59	62	109	65	9	36	47	43	36	32	33	31	33	39	33	43	37	30	34	27	27	27	32	25	37	32	16	[illegible]	20	20
52	46	49	29	57	54	54	59	51	62	40	37	76	81	35	20	43	45	46	38	37	33	54	27	32	35	40	38	25	29	31	33	27	24	24	17	9	16	28	28
29	63	41	44	47	58	65	47	53	43	52	37	45	60	41	9	35	30	35	44	37	41	37	40	40	24	40	51	37	36	34	39	34	31	26	13	17	22	25	29
44	56	36	31	27	55	[illegible]	35	53	53	47	55	56	55	34	14	16	27	45	42	39	54	71	46	35	29	47	49	40	43	52	36	34	31	25	13	15	24	24	16
38	31	40	37	39	49	54	74	71	48	44	40	48	45	37	31	37	43	12	48	50	52	42	52	40	29	45	38	32	33	29	40	36	32	34	24	19	19	34	22
40	43	62	37	51	42	61	69	67	66	52	50	44	56	56	43	31	44	21	24	51	57	57	57	45	39	47	40	35	29	25	35	35	38	35	24	25	17	25	21
32	42	37	55	34	47	42	39	51	62	45	26	45	50	41	53	56	55	53	18	42	60	54	40	31	35	36	34	36	38	28	28	27	23	33	18	21	15	23	17
41	52	64	54	45	37	42	45	40	50	37	24	45	31	56	50	61	57	84	24	31	54	49	36	38	47	35	32	28	38	39	33	29	23	15	23	25	27	33	16
47	46	49	62	47	27	35	53	36	57	40	26	40	50	39	36	36	59	67	58	18	54	63	44	40	34	30	37	26	26	38	30	26	25	28	20	20	31	34	20
39	41	46	48	47	48	18	29	49	39	44	43	45	36	39	31	31	33	42	57	57	19	26	49	42	40	34	24	28	35	33	31	33	31	31	34	24	21	33	33
44	44	41	42	40	45	21	30	40	32	42	45	30	31	40	24	33	33	37	37	53	62	50	32	26	19	24	36	33	37	32	36	36	33	28	29	36	29	31	30
44	32	43	38	41	52	31	27	44	27	35	50	35	40	33	26	36	29	34	29	37	48	50	43	51	60	50	28	12	16	24	34	37	36	42	44	29	29	27	20

*** THE AVERAGE ROUGHNESS FOR THE 1 X 1 DEG IS 7.76.

PHASE I ENDS AT 025559 ON 120877

****
*
* SUPS THIS RUN: TOTAL = 660.455 CPU = 129.607 I/O = 530.848 (INCLUDES CC/ER)
*
****

@ADD,P TERRAIN-D

@FREE 1.

@FREE 4.

@XQT T-TRIANGLES

ROUGHNESS INDEX MAP FOR 48°N LAT, 121°W LONG

FIGURE 16

ABOUT THE AUTHOR

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EW TRAINING IN THE FLIGHT SIMULATOR

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INTRODUCTION

The development of sophisticated, radar controlled antiaircraft weapons and the development of warning and countermeasure devices to allow aircraft to fight and survive against those weapons have changed the whole nature of air warfare. Now, warning and countermeasures devices are considered an integral part of the aircraft's armament, and training in the proper use of these devices is in turn an integral part of aircrew training.

With the reduced availability of fuel, and the resulting drive to move more and more aircrew training into simulators, there has been increased interest in the addition of realistic Electonic Warfare (EW) environments in new and existing flight simulators. It is the purpose of this paper to discuss the ways in which EW capability is and can be applied to these flight simulators and the way it interfaces with the other simulator subsystems.

Several general requirements characterize the specifications being generated in this field:

- The EW simulator must generate a threat environment, with groups of threat emitters (fixed and moving) at preprogrammed locations in the flight simulator's gaming area.
- Threats must be triggered by "movement" of the simulator into the vicinity of threats in the gaming area.
- The EW displays in the simulator cockpit must accurately reproduce what the students would see and hear if they were really in the situation being simulated (including equipment anomalies).
- The operation of all receiver and countermeasure controls must be accurately reflected in the EW environment displayed.
- The EW environment must be consistent with the other elements of flight environment presented to students in the simulator.
- Instructors should be able to use and program the EW simulation, using only the skills required to fly and fight in the simulated environment.

While the techniques described are applied particularly to flight simulators, the same basic approaches are equally applicable to Command Information Center (CIC) Room Simulators and Armour Crew Trainers.

TWO BASIC APPROACHES

Two basic approaches to the application of EW to flight simulators are used: Signal Injection and Emulation. In the first approach (Signal Injection) actual RF or video signals are injected into the input ports of operational type receivers or video processors, as shown in figure 1. These signals are generated with the exact characteristics that the real signals would have if they were received

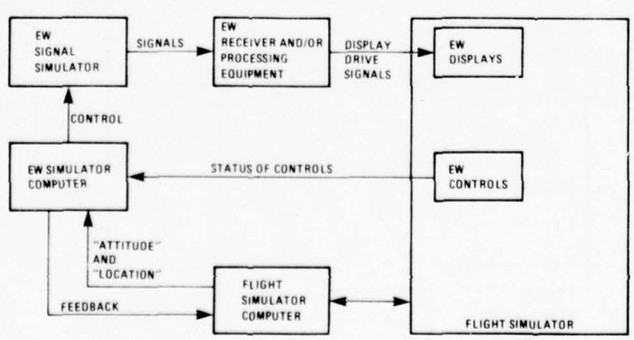

Figure 1. Signal Injection EW Simulation

by the operational equipment under combat conditions – with the aircraft in the attitude and location (relative to the simulated target) that the simulator shows at that moment. To achieve this, a computer controlling the EW simulator reads the status of the receiving and ECM equipment represented in the trainer, and the simulated location and attitude of the trainer in its gaming area. It then computes the exact signal parameters which would be seen by the receiver or video processor at that moment. The EW simulator is then commanded to generate those signal parameters – simulating many signals, each with the proper pulse and scan characteristics, signal strengths, direction of arrival, and (if applicable) RF frequency. This, of course, causes the receiver or video processor to generate the proper output signals to the displays which are presented to the student or students being trained in the flight simulator.

Signal injection is in many ways the simplest type of EW Simulation to add to a simulator, because the actual receiver or processing equipment used in operation is driving the displays the student sees in front of him. This means that the display characteristics are precisely correct – including any peculiarities in the way the actual equipment presents its data, and any systematic performance anomalies which the student will see later when he uses the same equipment in the real aircraft.

In the second approach (emulation) as shown in figure 2, no actual signals are generated and no operational equipment is used (except perhaps the actual displays). Rather, a computer calculates the data that would be present on the operator's displays if the aircraft represented by the trainer were in the simulated position and attitude of the trainer in its gaming area.

At first glance, this seems to be a more simple approach, but now all of the little "quirks" of the operational equipment displays must be reproduced in order to preclude a negative training effect. It is a fairly simple task for a computer to place alphanumeric characters or lines on a cathode-ray tube (CRT) screen; but when these must jitter around in different ways as a function of signal density and relative location (as is the case in some real equipment), the task becomes more formitable.

SCENARIOS

In both Signal Injection and Emulation, threat scenarios are stored in the EW simulator computer. These scenarios comprise large numbers of threats located at various, appropriate positions throughout the gaming area. Any of these may be moving. The platform simulator is "flown" through this gaming area, and as threats are encountered, they are displayed to the student(s) in the simulator. As the simulator's "position" comes closer to the threat signal "location," the threat signal may change modes and the simulator will be "fired upon" if it gets into an appropriate position relative to the threat. The EW computer will analyze the effects of countermeasures applied at all stages in this process, determining if the threat will fire – and if it does, whether or not it hits the simulated aircraft. Damage assessment, or "near miss" information will be fed back to the platform so this can be applied (if appropriate) to other systems in the simulator. For example, a near miss could require the visuals to show a burst or an undetonated missile flying past in the appropriate direction.

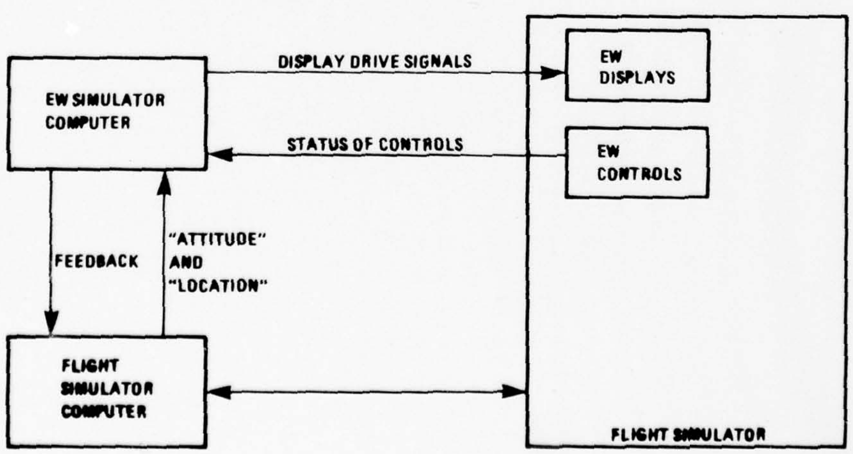

Figure 2. Emulation EW Simulation

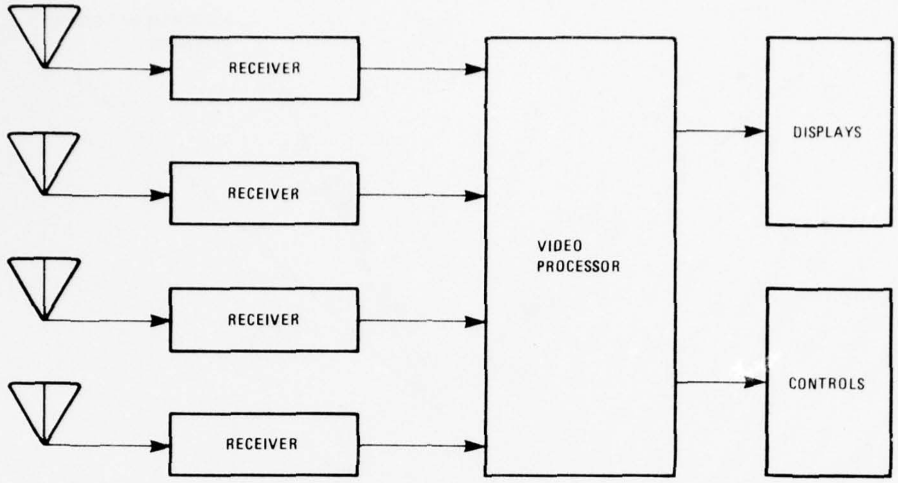

Figure 3. Functional Block Diagram of Radar Warning Receiver

DATA INPUT TO SIMULATOR

The EW data must be input to the simulator in ways that accurately reflect the way real data enters the EW equipment in the simulated aircraft. While the locations of the "aircraft" and the "threats" in the gaming area may be known within ±50 feet, it would be highly inaccurate to reflect this accuracy in the cockpit displays. As an example, consider a typical digital Radar Warning Receiver (RWR) with a block diagram as shown in figure 3.

This RWR must determine the type, mode, and location of threat signals relative to the aircraft from the information it receives through its four antennas.

Each antenna has a gain pattern as shown in figure 4. (Note that this is a cosine pattern.) The output amplitude of each antenna is thus approximately proportional to the cosine of the angle between the antenna boresight and the signal direction of arrival. Since the antennas are mounted on the "four corners" of the aircraft as shown in figure 5, the video processor can work the vector equations (figure 6) and determine the resultant signal strength and azimuth of arrival of each signal (hence the range and bearing to the threat). Of course, the processor must also determine the signal type from the characteristic parameters of the received signal.

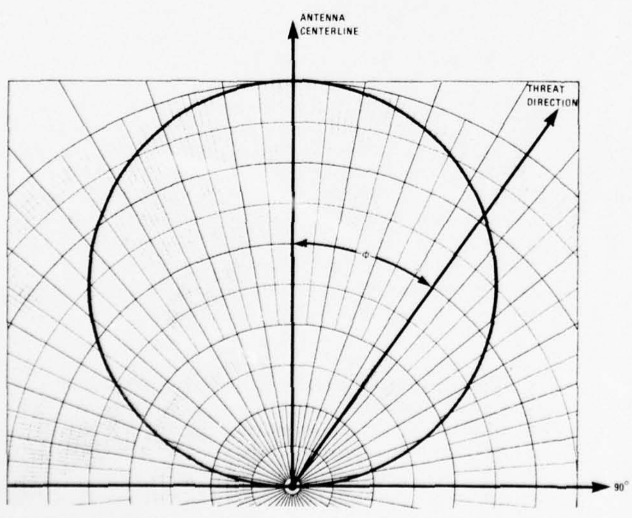

Figure 4. Typical Warning Receiver Antenna Pattern

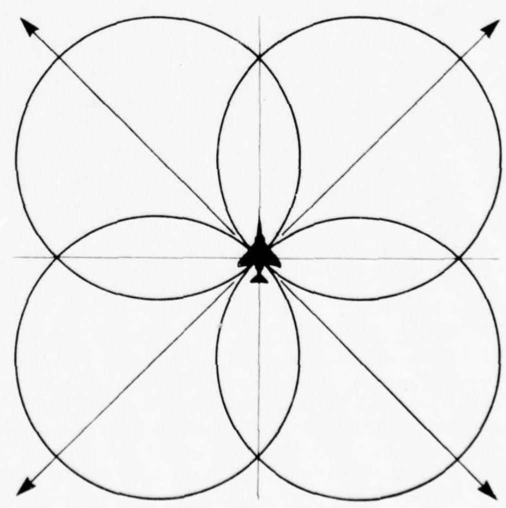

Figure 5. Aircraft Antenna Patterns

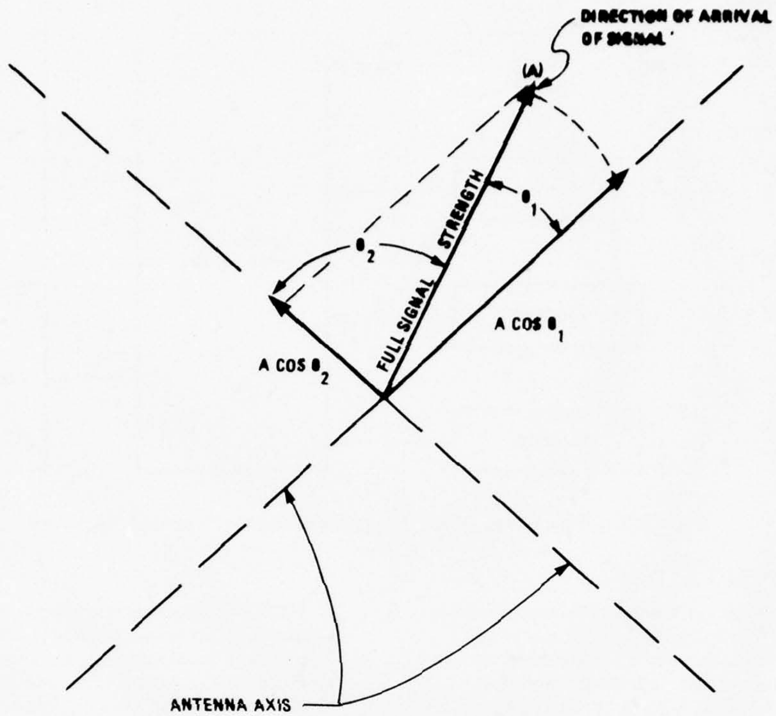

Figure 6. Components of Signal Vector in Each Antenna

That's easy so far, but there are some problems. The first is that the signal may not be within the plane of the four antennas and the aircraft may not be flying straight and level. So, the computer must work the coordinate transformation shown in figure 7 to determine the spherical angle between the signal and each antenna boresight. * Two interesting examples come immediately to mind:

- If the aircraft is upside down, the RWR display will be reversed.
- If the aircraft is in a 90 degree bank on a course perpendicular to the threat signal vector, all of the antennas will see the same signal level – so no valid display can be made to the student in the cockpit.

These are extreme examples, but they do serve to illustrate the display distortion effects that must be considered if a realistic data presentation is to be generated.

The other major effect is, of course, terrain occlusion of threat signals. Whenever the simulator approaches a threat emitter location, the computer must check that the vector between the aircraft location and the threat emitter location does not fall below the "surface of the terrain" in the gaming area (for simulators with that capability) before a signal is displayed. (See figure 8.)

* The actual antennas are also slightly depressed from horizontal plane.

PROGRAMMING THE EW SIMULATOR

While the detailed programming techniques applicable to individual simulators vary because of many technical and mission related factors, there are some requirements which they share. The most important of these is that the instructor be able to program the EW environment without having to learn any skills other than those required to fight in that environment and to teach others to fight in that environment. This specifically excludes direct knowledge of the parameters of signals associated with individual threats. The instructor must, therefore, be able to specify threats by threat type only (e.g., an SA-X) – and the simulator itself must then set up the proper pulse, scan, and RF frequency for each of the radars associated with the SA-X, or in some other way establish the information against which the threat displays will be generated.

The instructor must also be able to quickly and easily place those threats in the simulator's gaming area, either by specifying the gaming area coordinates at which the threats are to be placed or by placing threats in some graphic way. An example of a graphic technique is the movement of a threat symbol by use of a track ball – over a map of the simulator gaming area shown on a CRT.

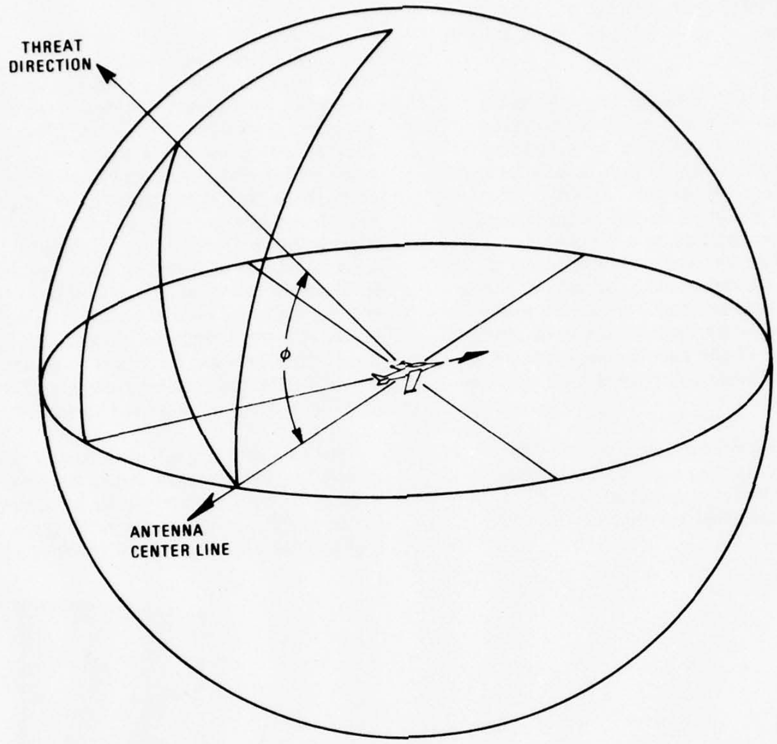

Figure 7. Determination Angle from Signal to Antenna Boresight

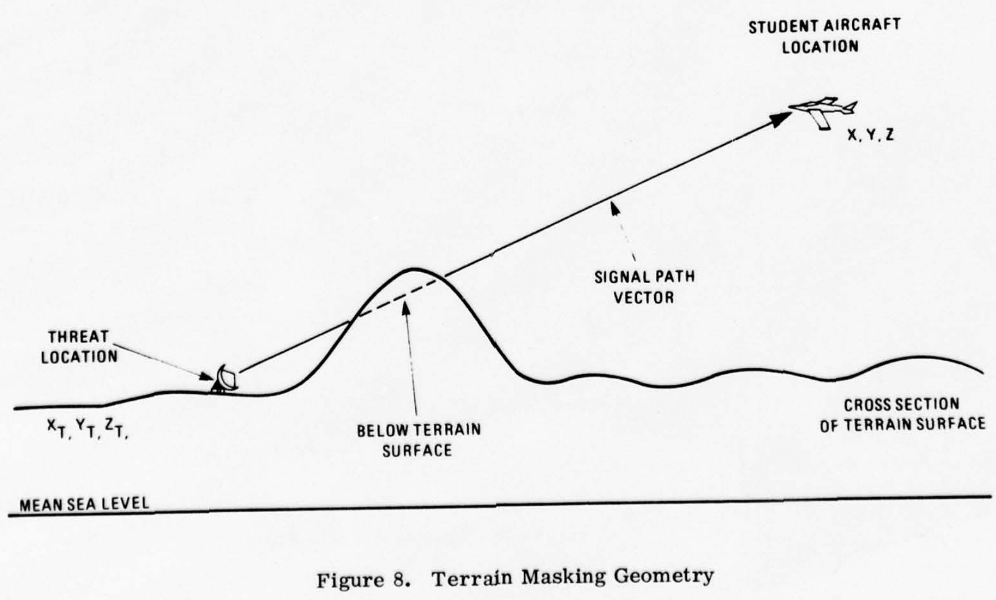

Figure 8. Terrain Masking Geometry

Another desirable feature is the ability to place groups of threats (for example, a complete defended airfield or city) with one set of coordinates or the placement of a single symbol with the track ball.

The above stated programming requirements assume that the instructor will be programming the EW simulator by the placement of individual threats or groups of threats – which is helpful for some types of training. However, another (perhaps more common) situation is the requirement to train the student to operate in a "typical" environment, or in the environment expected at some specific place on the earth. In both of these cases, the actual threat scenario would be prepared for the instructor by individuals with current and expert knowledge of the threat environment to be simulated. So the instructor need only use the provided environment.

But whether the instructor must create the environment, or merely use a preprogrammed environment, he can still concentrate on the instruction and evaluation of combat skills – not on EW skills as such.

EW TRAINING VS. FLIGHT SIMULATOR TRAINING

Despite the fact that the EW environment is now considered an integral part of the combat environment, it is often highly desirable to separate the flying part of the simulator from the EW part to conduct different types of training. Therefore, it often becomes yet another requirement of the EW simulator that it be usable with or without the flight simulator. The EW simulator shown in figure 9, which is in use with a flight simulator in Europe, has provision for the use of a parallel set of warning receiver displays (shown in place in the photograph). Since the EW simulator contains its own computer, which stores the whole EW environment gaming area, those front panel displays can be made to operate just as they would in the cockpit – by causing the computer to "fly" any desired course through the gaming area.

But the real payoff still comes when the system is used in its primary role, to provide students with as close as possible to a combat experience in the flight simulator by adding the EW environment to the other sensory feedback provided.

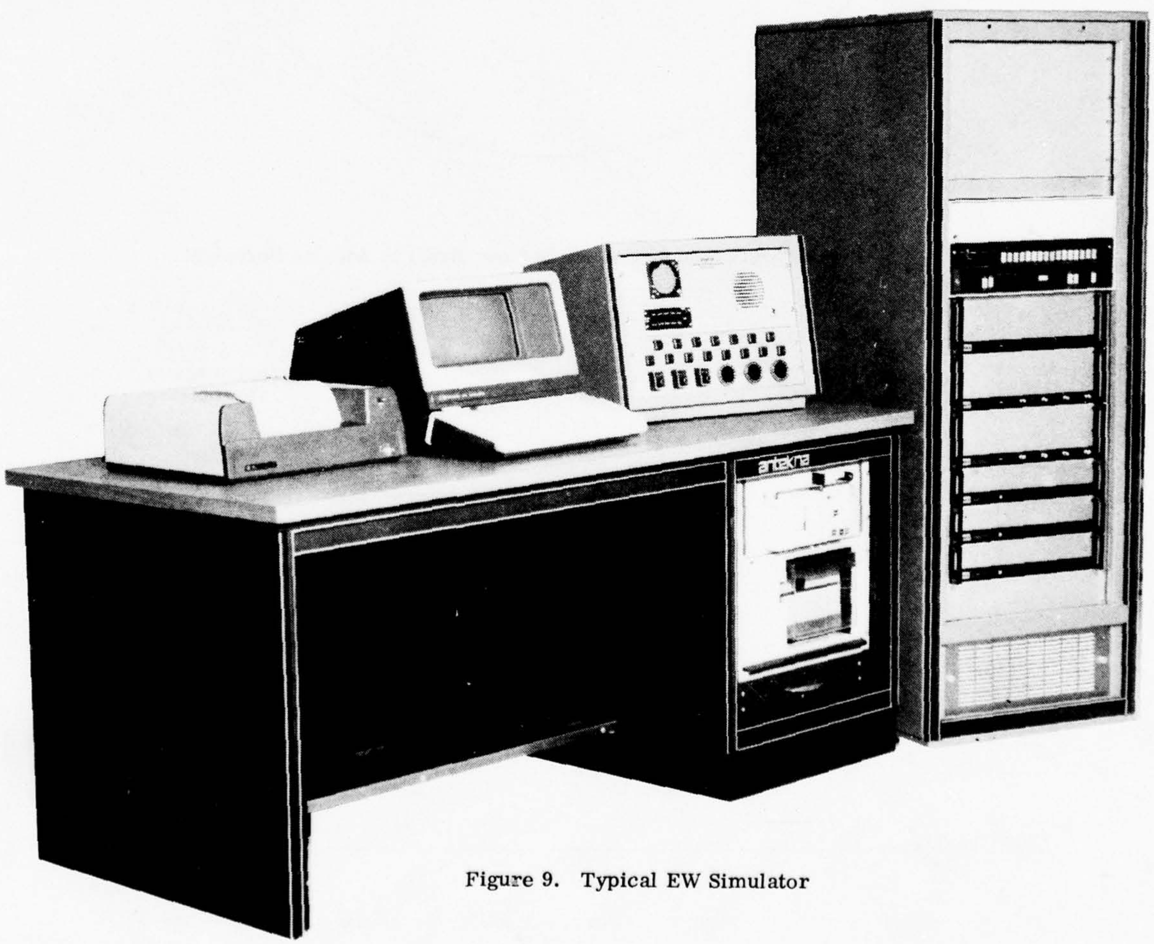

Figure 9. Typical EW Simulator

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A SIMULATED APPROACH TO EA-6B EW AIRCRAFT TRAINING

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The EA-6B Prowler is the U.S. Navy's most sophisticated electronic warfare aircraft. Designed to employ high-power jammers and other electronic countermeasures to disrupt enemy radar and communications and thus screen strike force aircraft from surface-to-air missiles, the EA-6B also is used to protect surface ships from radar detection by enemy aircraft and from cruise missiles.

Operation of the complex, advanced electronics gear on the EA-6B demands a high degree of crew training and readiness. In response to this requirement, Sperry SECOR of Fairfax, Va., has designed and is building an EA-6B Weapons System Trainer under a prime contract from the Naval Air Systems Command. The trainer will help ensure that U.S. Navy pilots and electronics countermeasures officers (ECMO's) receive realistic training in the operation of their aircraft.

The EA-6B trainer which will be the U.S. Navy's largest and most technically advanced flight simulation training device is scheduled for installation at the Naval Air Station, Whidbey Island, Washington. At present, delivery is projected for 1979. Simulation of the EA-6B aircraft involves complete aerodynamic modeling of aircraft performance, including all flight instruments and aircraft systems. The trainer also provides simulation of all EW systems and on-board avionics, including a digital radar landmass simulation. A computer generated image provides an out-the-window display for shore-based and carrier operations. Full simulation of the electromagnetic environment in which the aircraft will operate is also provided. The training device is designed to operate in two modes: integrated full-crew flight and tactics operation; and independent operation of flight or tactics subsystems for specialized training.

The Navy will realize substantial savings in training costs by directly substituting EA-6B trainer flight hours for actual aircraft flight hours. These savings will accrue from: reduced aircraft flight hours; lower personnel and logistics costs in maintenance and expendables; accident reduction; extension of aircraft life through flight hour reductions; and improved and increased training capability. The EA-6B WST is shown in Figure 1.

The hourly operating cost of the EA-6B trainer is projected to be 10 percent of the hourly cost of actual aircraft operation. Based on the Navy's plan to substitute 3,400 simulator hours for 1,930 hours of flight time from 1980-1981, a total savings of about $3.2 million could be possible. This projection is based on the experience of DOD and commercial airline users. It assumes that the capital costs of an EA-6B aircraft (fly away configuration) and an EA-6B trainer are roughly comparable. The potential dollar savings are realized primarily from flight hour reduction and accident reduction. Other cost saving factors such as improved training and lower maintenance and support costs offer potential for additional savings.

Other training benefits, too, contribute to the cost-effectiveness of this simulator. Some of these are difficult to quantify and can be estimated only by employing assumptions based on empirical data. For example, improved and increased training capability is achieved by providing training scenarios that would be impractical to produce using the actual aircraft. The simulator permits training in emergency situations, such as engine fires on takeoff, which would not normally be induced in the actual aircraft. Also, certain combat situations can be duplicated in the simulator with exact fidelity and realism which are

not possible in the aircraft except during wartime conditions. For example, the EA-6B trainer provides the capability to simulate training missions over contested areas and enemy territory. Also, the trainer can reproduce wind, turbulence, and visibility conditions in simulated flight with precisely controlled and realistic fidelity. These same weather conditions may never be encountered on actual training flights or would more likely be avoided for reasons of safety.

Major components of the EA-6B trainer include: a modified EA-6B aircraft cockpit/student station; six degree-of-freedom motion simulation system; a dusk-night visual simulation system employing computer generated image technology; a three-position instructor station for control of the flight and tactics scenarios; a main simulation computer complex which has 1.3 megabytes of core memory and 1,000 megabytes of disc memory. A block diagram of the EA-6B WST is shown in Figure 2.

In addition, the device has a maintenance intercommunication system, hydraulic power units for the motion and flight controls, and other support equipments for test and repair.

The heart of the system is the computer complex and associated software programs. These integrate the various simulator components and provide the basis for operation and control of the device. The software development effort is a major achievement of the EA-6B program.

The EA-6B trainer computer complex consists of four Central Processing Units (CPU's), including their associated peripherals and a four-way shared memory. Each of these CPU's controls a distinct functional subsystem: (1) master computer for input-output, control of instructional features and synchronization of all four computers, (2) flight computer for aerodynamic calculations and motion system control, (3) tactics computer for control of ECM functions and implementation of tactics and instructional features, and (4) digital radar landmass simulation computer for implementation of the APQ-129A radar and control of input-output flow to cockpit and instructor station displays. A fifth computer, independent of the four, is used for on-site software development. A sixth computer is used to synthesize the visual scene. In addition to allowing for orderly development of software functions, this architecture allows for degraded mode operation in event of computer failure. For example, should the tactics computer malfunction, training for pilots and the ECMO-1 can still continue. If the master or flight computer fails, ECMO 2 and 3 training will not be interrupted.

The EA-6B simulator incorporates the most modern features of digital flight simulation technology. These features permit simulation of the entire envelope of aircraft aerodynamic performance and flying qualities, including stalls and spin. Simulation of the full range of engine performance, all aircraft, auxiliary systems, ground handling, carrier catapult launch and recovery wing fold, ejection seats, G suits, environmental control systems, and oxygen, are included in the trainer. All flight instruments and communications/navigation systems are also simulated. The device includes digital radar landmass simulation of the AN/APQ-129A search radar. This system contains 1.6 million square miles of landmass data base storage; terrain and cultural features, including shadows, refraction and earth curvature, far shore brightening, and range attenuation; and moving targets and emitter occulating.

ECM simulation covers the AN/ALQ-99 Tactical Jamming System, AL/ALQ-92 Communications Jammer, AN/ALQ-126 Defensive Jamming System and AN/ALE-129 Chaff Dispenser.

The EA-6B trainer simultaneously simulates fixed and moving tactical emitters. These simulated emitters are provided in sufficient quantity to train EA-6B aircrews to operate effectively in a real world tactical environment. Various types of

emitters are programmable (e.g., search radar, communications facilities, fire control radars), with each having the appropriate electromagnetic characteristics and signal strength location in the gaming area.

The visual presentation is provided by a three-window, two-channel, dusk/night computer generated visual image simulation system. Realistic visual presentations of NAS Whidbey Island and the USS Nimitz are provided for training in shore-based and carrier operations. Integration of visual scene elements, including lights, beacons, etc. and proper correlation of radio, enhance the realism and training effectiveness of the device. The visual scene will display carrier dynamics up to sea state 9. A generic countryside is included, with horizon and sky for cross-country navigation missions.

The hostile area scene is a unique feature of the visual simulation. It includes special effects such as antiaircraft fire, SAM launches and flares. As part of the visual simulation, developmental work is being done to provide a visual scene which includes a KA-6D tanker aircraft with drogue for training in in-flight refueling operations of the EA-6B aircraft crew.

With all these capabilities and technical features, the EA-6B simulator can have up to three instructor operators to coordinate and control the training scenario in integrated flight and tactics operation. The instructor station includes five graphic CRT displays with interactive terminals. Also, repeat displays of the visual scene, AN/APQ-129 Radar, digital radar land-mass simulator and AN/ALQ-99 Tactical Jammer are provided at the instructor console. The instructor station is designed to provide maximum flexibility in trainer operation. Ten sets of initial conditions are included to accelerate the start-up of training. A number of pre-programmed demonstration maneuvers are provided. Other special features include twenty-minute dynamic replay, with fly-out capability and computer evaluation of trainee performance in flight and tactics mode.

The EA-6B weapons system trainer will provide better training at substantially lower costs over traditional training techniques. It offers new opportunities to the EA-6B training community in utilizing the extensive range of features and capabilities of the device. By integrating this flight simulator into the training cirriculum, the U.S. Navy's Naval Air Systems Command will take a major step forward in providing vitally needed qualified aircrews for the EA-6B.

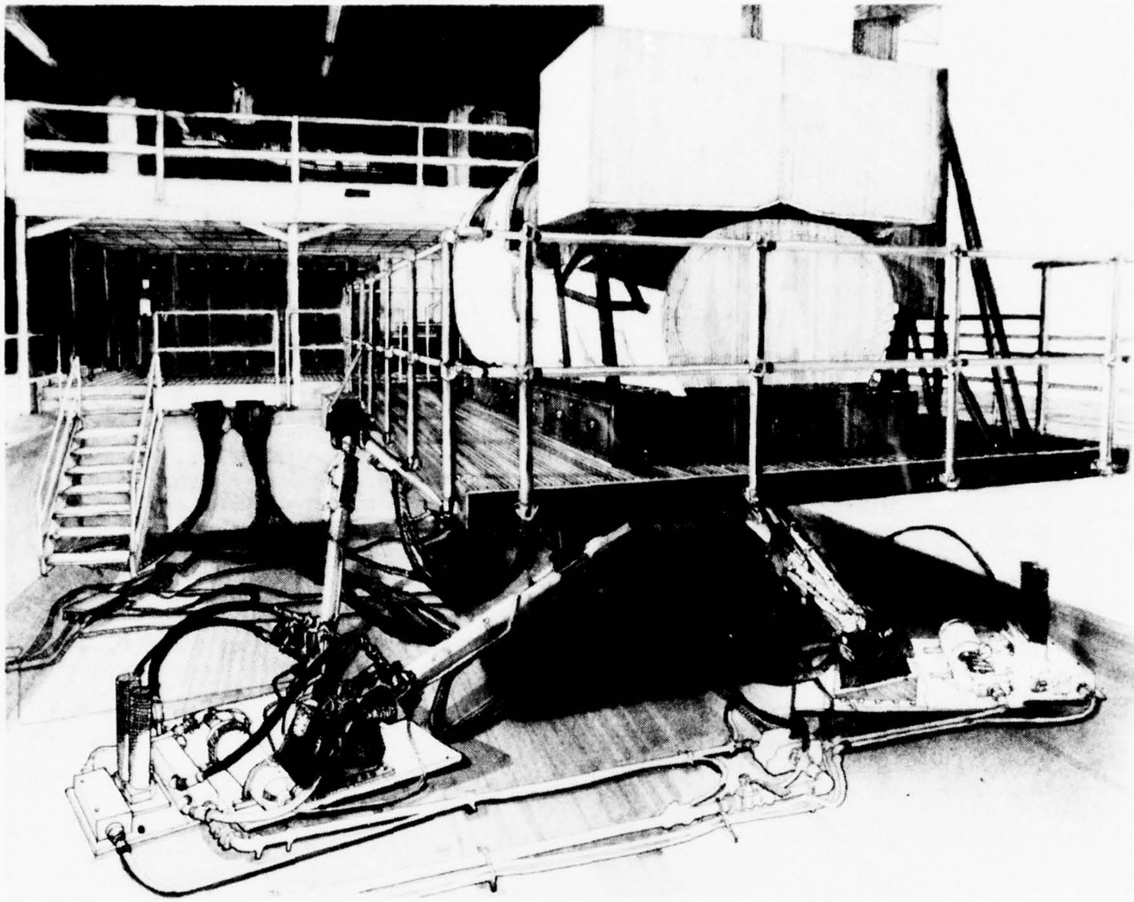

Figure 1. EA-6B Weapons System Trainer

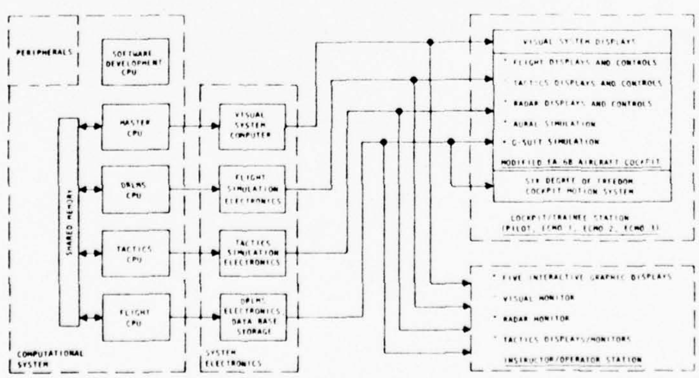

Figure 2. EA-6B Weapons System Trainer System Block Diagram

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TRAINING EFFECTIVENESS VERSUS SIMULATION REALISM

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ABSTRACT

Simulation is of continually increasing importance in training. Cost, energy, and safety are among the driving factors. The goal of simulator development is to provide increased training effectiveness. This is frequently considered to be almost synonymous with increased simulation realism. Actually, the relationship between simulation realism and training effectiveness is far from simple. Realism itself is not a simple scalar – there are types of realism, and functions of realism must be considered in multidimension space. This applies to cost as well as to training effectiveness. Questions in this area may not be difficult to answer, once they are asked. There is a continual danger that important decisions will be made, and made incorrectly, due to failure to ask the pertinent questions. This paper considers results from simulation experiments and training activities over the years. In particular, surprising and non-intuitive results are examined. The major goal is to illuminate areas of pertinent questions, although in some cases tentative answers are presented.

INTRODUCTION

The title of this paper can be interpreted in two ways. It implies a relationship – realism is the abscissa and effectiveness the ordinate and the nature of the functional relationship is to be explored. Or the title can with equal validity be interpreted as implying an adversary relationship, that realism actually degrades training effectiveness. The following discussion covers topics under both meanings.

I was a participant at a meeting at Wright-Patterson Air Force Base some time back. The topic was planning of an electrooptical viewing system (EVS) simulation for training. Many aspects of actual EVS displays were discussed, prompting numerous questions of how to achieve realism in regard to the area under discussion. Finally, an Air Force representative raised the issue that, instead of pondering how to achieve realism, we should ask how to achieve training. We then started making some progress.

There's a rather obvious reason why we frequently fall into the trap of considering simulation realism as the end, rather than as the means to an end. Given that effective training can be achieved with the real system in the real environment, it follows that a simulation providing 100 percent realism would unquestionably provide effective training. It does not follow that 100 percent realism is necessary. Further, given a system in which the realism is short of this goal, it does not follow that it is necessarily desirable to improve realism in one aspect, with no change in other areas.

WHAT IS REALISM?

We do not usually ask this question. We know what realism is, and consider the question of the degree to which we need it, and how to obtain it. Maybe the question itself should be asked more frequently than it is.

During an experiment on tracking about the roll axis(1) there were three modes of operation. In one, the subject saw only a front display, and his seat was stationary. In another, he saw only the front display, but received roll cues from valid seat motion. In a third, the seat was still, but two side displays were added to simulate peripheral vision sensing of roll. The results of major significance to the current discussion were that performance in modes two and three differed significantly from mode 1, but the results for these two modes were very close. This included comparison of both the amplitude and phase of the transfer functions of operators involved in the experiment.

It would not be expected that knowledge of roll rates and magnitudes obtained by these two routes (Figures 1 and 2) would necessarily lead to essentially identical performance.

Some experiments with a certain type of stroke victim have provided additional insight(2). In some cases, the effect of stroke is to completely eliminate peripheral vision – to break the link between "Eyes" and "Visual Perception" in Figure 1. The subject can only see the contents of a narrow tunnel straight ahead. Nevertheless,

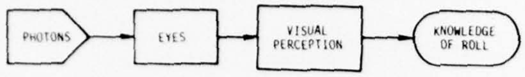

Figure 1. Vision Perception of Roll

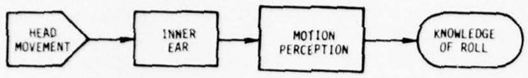

Figure 2. Motion Perception of Roll

if he is seated in a chair and objects are moved in his blind peripheral region, he reacts as though he senses roll!

This strongly suggests that the perception of motion from objects moving in the field of view, while it involves the retina and the optic nerve, does not involve visual perception of the motion, and derivation of observer motion knowledge from that. It must be more akin to the diagram shown in Figure 3. Now, at what point in this diagram is "reality," insofar as it affects the roll tracking task. The subject could get roll information from other sources – the experimenter could inform him of roll parameters – but this would not provide the same performance. As a tentative hypothesis, if the output of the "Motion Detection" block is valid, realism is achieved, independent of the input providing this output.

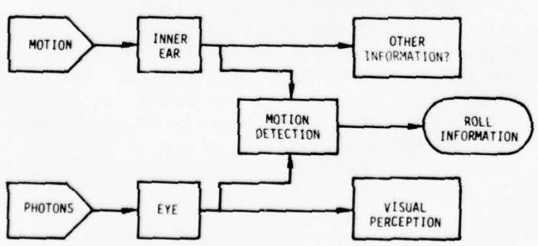

Figure 3. Roll Perception - Composite Block Diagram

REALISM – CHOOSE YOUR ROUTE

Perception of distance is very important to many CGI training activities. This is an area in which past CGI systems have not had notable success; further, it is an area in which potential improvement may be very difficult and expensive. It is important to understand just what is the realism we're seeking here.

Gibson(3) states that the mode of perception we normally think of first, "Apparent size of familiar objects..."is"... far less important and fundamental." It is "... not the kind of distance perception which occurs in the everyday visual world." His analysis leads to the statement, "The perception of depth, distance, or the so-called third dimension, is reducible to the problem of the perception of longitudinal surfaces. When no surface is present in perception because of homogeneous retinal stimulation, distance is indeterminate."

Interesting. Many years prior to CGI, Gibson put his finger on a major problem, the "homogeneous retinal stimulation" found on past systems. The solution, however, cannot be just any surface nonuniformity. The distance information is contained in the "stimulus gradient."

The source of the stimulus gradient may be a texture gradient (the one normally thought of initially when this problem is attacked); it may be aerial perspective; it may be gradients of velocity and direction in a dynamic situation; it may be (for short distances) gradient of binocular disparity; or it may be convergence of parallel lines or structures. One can envision a diagram similar to Figure 3, but with the various visual gradients entering, and a generalized "stimulus gradient" (on which decision and action are based) leaving.

In this case, it may be valid to consider this stimulus gradient as the "realism" we are after. If an actual scene provides this gradient in the form of a texture gradient, and a simulation provides the same gradient by using parallel line convergence, it will not look "natural," but in a training sense is realism degraded?

Perhaps we should determine the approach which will give the most valid and realistic stimulus gradient, and deemphasize considerations of which looks most natural.

MATCHED NONREALISM

In one area, there is no question as to what constitutes realism. If in the real world some object whose position provides me with information should move, then the photons from that object reflect the movement with a delay limited only by the speed of light. Similarly, if the dynamics simulation calls for the onset of roll to occur at a given instant, then a realistic motion system would provide it at this instant, with no delay.

A system being installed by NASA (the Differential Maneuvering Simulator at Langley AFB) had a cockpit motion system with several degrees of freedom. It had a camera-model visual system with servoed cameras. The display system included a servoed projector. Maximum realism is desirable – absolute realism requires zero delay – so all delays in the system were reduced to their practical minimum. The subjective effect of flying the system was highly unrealistic and unsatisfactory. They then determined which element in the system had the maximum irreducible delay, and they increased all system delays to match it. The result was a satisfactory system.

Any technique has limitations. This same approach was later used on a different system and the results were unsatisfactory. The motion platform in this case had very sluggish response. When the visual response was slowed to match it, the lag was so much greater than that of the aircraft dynamics that realism was impaired. When delays were adjusted without regard to the motion system, the results were satisfactory – the feedback from the visual scene motion was so much more powerful than that from the platform motion as to overpower the latter.

WHOLE-HOG – FINE IF YOU CAN GET IT

Consider a nuclear power plant simulator for training operating personnel. It can readily be built the exact size, shape, color, and even smell of the actual operating room. All meters, indicators, and actuators can be those used in the actual system, or can be indistinguishable from them. The simulation software can readily incorporate algorithms reflecting the actual plant operation to the point where the effect of any actions taken by the operators, or in response to simulated changes in loading or simulated malfunctions, can be precisely those which would result in an actual system under the conditions being simulated. Thus, there is no point in asking, "Is this degree of realism necessary?" It would cost more to determine it is not required, than to go ahead and give one hundred percent realism.

Navigational radar simulation comes close to being in the same situation. The resolution is such that there are far fewer potential distinguishable elements on a display than for a visual scene, and the update rate leads to a much greater allowable processing time per scene. It thus becomes feasible to supply very close approximations to full realism.

CAN IMPROVED REALISM HURT?

We have already considered the case of various system delays, where we are better off to degrade the response of the faster (more realistic) elements so they match the slower ones. This same type of effect must be considered in other areas of realism.

Figure 4 shows a cylindrical storage tank simulated by two techniques. In one case, each face has a tone as determined by its orientation relative to the illumination. In the second, the technique of shading tone across faces is applied to simulate smooth curvature. The actual range of tones is the same on both – yet it seems to be much greater on the flat-face version, giving a richer set of cues to orientation and to illumination direction.

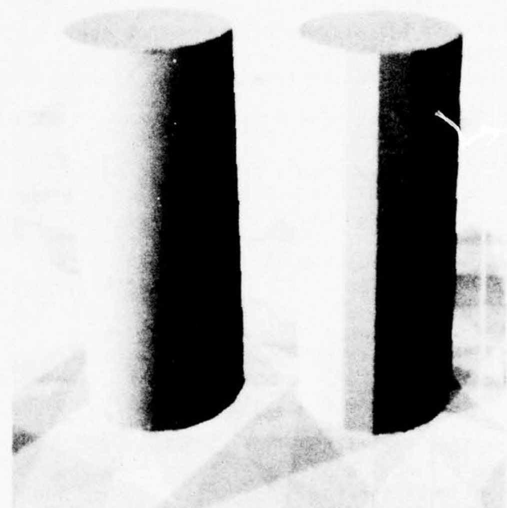

Figure 4. Cylindrical Tank with and without Curvature Simulation

The human perception system is exceedingly insensitive to gradual continuous changes of tone or intensity. This is not a deficiency. As pointed out by Land[4] it is a very essential characteristic of the system which enables us to perceive colors as constant under wide variations of lighting. An

actual tank in the sun has gradual gradation of tone, as simulated with the second system. The actual scene differs in another aspect of realism – the actual intensities are several orders of magnitude brighter than can be achieved in CGI display systems. If we could achieve the actual brightness, there would be no question, we would want the actual shading. Being unable to match real-scene brightness, perhaps we do not want real-scene shading. We are not trying to arrive at a validated answer here. The point being made is that we should at least question whether to use maximum available realism of each aspect of the simulation with no consideration of the range of effects on training cues which will result.

The T-37 simulated on the ASPT system using a large number of faces and the curvature algorithm, is extremely effective. An early viewer of the system thought it was being produced separately from CGI by a model and television camera. However, another Air Force observer who flew the system in its early operational phase, said he felt that this algorithm, in making invisible the face edges with which the aircraft was defined, was throwing away information that could be valuable in training – cues to replace those normally extracted from aircraft skin texture.

DELIBERATE DISTORTION OF REALISM?

When Navy pilots are landing on a carrier, critical glide-path information is derived from the "meatball," or Fresnel lens landing system. This was therefore modeled on the 2F90 visuals, used by the Navy in Kingsville, Texas, for pilot training. This CGI system is an early one, with rather limited resolution. At the distance where pilots normally expect to start extracting information from the meatball, they were unable to do so – it did not subtend enough pixels on the display. The solution – it was made less realistic. Its modeled size was made a function of its distance from the pilot – larger than life at a distance and decreasing to actual size at close distances. Result – satisfactory training.

An article by one of the Navy's training personnel at Kingsville[5] is instructive in this regard. Published in Approach, the Naval Aviation Safety Review, it states: "Student instruction in WEPS stage was instituted in April 1975. After a short period of instruction, it was evident that the students who had had several hops in the simulator were, to a significant degree, outperforming those who had not." Later, "The system has enabled the instructor to provide the student aviator with a high degree of realism..." Note – that important word, realism. The article includes several pictures showing a bomb run over the Navy-generated data base used for this training. The ground is covered with orthogonal sets of stripes resembling a checkerboard. Realism? The author obviously did not mean pictorial realism, but realism as it applied to his task, to train the pilots.

REALISM TYPES AND COMBINATIONS

Consider the visual scene realism required for a couple of types of training.

Landing an aircraft requires that the proper glide slope be maintained on approach; that descent be arrested at the proper point on the glide slope; and that rate of vertical descent be held very close to zero as airspeed decreases, culminating in the goal of touchdown at the desired point, at the proper airspeed, and with as close as possible to zero rate of vertical descent. Mastery of this sequence in a simulator requires close to perfect realism. The spatial and perspective validity of the simulated scene must be exact. The response of the visual scene to the trainee's aircraft control cannot be approximate – it must be precise. Every student pilot has many times executed a perfect landing, meeting all above requirements, but one foot above the runway surface – and then dropped and bounced, hoping no one was watching. This illustrates the degree of realism required.

Consider next the training of navigators for nap-of-the-earth helicopter flying. In this type of operation, the aircraft avoid roads, rivers, and settlements. These would greatly ease the navigator's task, but they would also subject the helicopter to sighting by the enemy. They fly low; below hills, even below the tops of trees. Thus, the navigator cannot look down on a panorama and locate standard map features. The navigators must base their decisions on extremely subtle visual cues – the lay-of-the-land as expected from map contour information, a glimpse of a pond through the trees, etc. To train navigators for this task essentially perfect realism is needed – the smallest variations in elevation of the actual terrain must be faithfully reflected in the simulated visual scene. Slight color variations can be very significant. The scene must look exactly as the terrain would from any viewpoint and attitude.

Here are two training requirements, each requires as close as possible to perfect realism, yet quite inexpensive solutions to each are in use.

CGI systems producing low-detail scenes which have fully valid dynamic and interactive

fidelity are providing effective training in tasks such as takeoff and landing and weapons delivery. These include calligraphic displays and limited-capability solid-object display systems.

Effective nap-of-the-earth helicopter navigator training is being provided by systems based on viewing motion pictures taken during flights through the training area, with increasingly difficult assignments as the training proceeds. There is no interactive capability – the scene proceeds independently of the trainee's actions – but none is needed. The fully valid pictorial fidelity needed is provided.

COST VERSUS REALISM

To provide a pictorial indication of the relationship between realism and cost, it is necessary to use at least a two-dimensional plot. Figure 5 shows the nature of the relationship. The point at the lower right, designated "A," has limited pictorial realism but full dynamic and interactive realism – this is the inexpensive region occupied by the flight trainer referred to above. The point near the upper left designated "B" has no interactive capability but excellent pictorial realism – it is the inexpensive region occupied by the nap-of-the-earth navigation training system.

The system complexity, and thus cost, rises steeply when a system must provide both types of realism simultaneously. The current trend of systems, particularly for the military, is along the right edge of the figure, moving back in the direction of continually increasing image fidelity. There is no question that training in tasks such as target identification and weapon damage assessment requires pictorial realism comparable to the navigation task discussed above. If it requires this simultaneously with highly dynamic and interactive realism, then the requirements fall in the right rear of the plot. In all such cases, however, it is important to consider whether the secondary type of realism can have relaxed requirements, as this can drastically lower system complexity.

REALISM CAN BE HARMFUL TO YOUR HEALTH

This one still hurts when I think about it. It was back in 1969 or 1970. We had our real-time laboratory system working, and driving a wide-screen display in front of a simulated cockpit. We were expecting an important group of vistors – potential users and customers. We were modeling the world they would fly in.

CGI scenes had been criticized for looking too stylized, too cartoonish, unnatural.

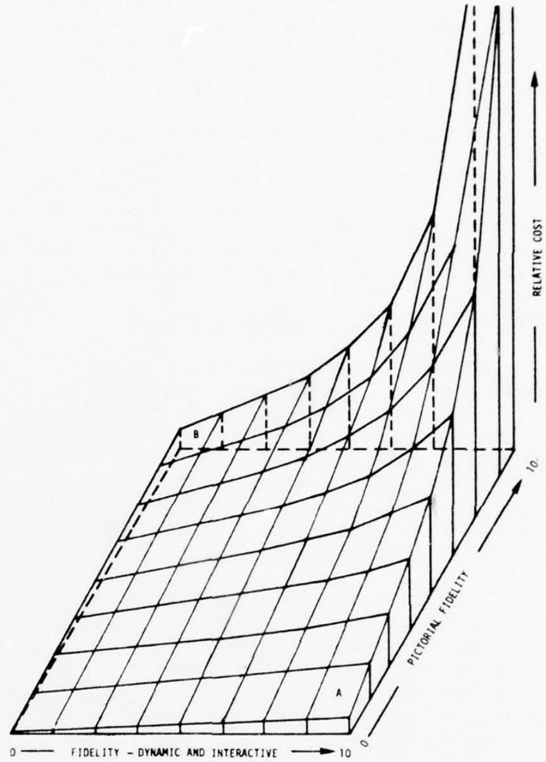

Figure 5. Visual Scene Simulation Cost Versus Fidelity

We did all we could to cure that. Fields were made a variety of shapes and sizes – not just square. Roads were laid with varying directions, not in parallel patterns. We did all we could to make things look natural – to add realism.

Black Monday arrived. The vistors flew the system. Monday afternoon we had a debriefing. Every pilot who had flown the system had praise for many aspects of the simulation, but stated he was "unable to maintain his glide path." No one knew why, but all agreed that unless we could determine why, and fix the problem, this type of system might be worthless for training. Then a couple of them made the comment which provided the critical clue. They said they were more successful in maintaining the desired glide path when shooting a landing on the carrier, where there were no surface cues at all. This indicated our land scene was providing counter-cues.

We redid the terrain. We made all fields square, and roads parallel. We took all the

naturalness out of it. Two days later, Wednesday, we had the modified scene up and running. Many of the visitors were still at the plant, and were persuaded to fly it again. They were amazed. A typical comment, "I don't know what you did to it, but you sure fixed it."

In retrospect, we know what we did. We did not have many scene edges then. In Wednesday's scene, those we had were devoted to providing Gibson's "stimulus gradient" derived from the parallelism of scene features, rather than destroying this cue in an attempt to achieve a more real appearance.

SOMETIMES IT DOES NOT SEEM TO MATTER

In an interesting experiment several years ago(6), a simulator was available in which realism could be varied in three significant aspects. The scene could be monochrome, or full color — color is more realistic. The resolution could be varied — finer resolution is more realistic. The display could be collimated, or a real image on a screen — collimated is more realistic.

The experiment was to determine the effect on performance of these variations in realism. The subjects were experienced pilots — not students. The measured performance parameters included rms deviation from correct glide path, deviation from planned touchdown point, and vertical velocity at touchdown. The greatest surprise in the results was that the full range of variation in the factors affecting realism produced only minor perturbations in the measured performance.

Lateral localizer error, for example, ranged from an rms value of 0.7 degree with screen display in color, to an rms value of 0.9 degree with the collimated display in monochrome.

Mean touchdown rate of descent with collimated optics was 3.58 feet per second with standard deviation of 1.52 feet per second, and for the real-image system the rate was 4.33 feet per second and deviation 1.98 feet per second.

The only statistically significant result reported as due to decreased resolution was in increase from 0.33 degree to 0.35 degree in rms glide slope error.

There was no difference in results of statistical significance between monochrome and color.

Gibson provides some insight into results such as this(3). "The stimulus-variable within the retinal image to which a property of visual space corresponds need be only a correlate of that property, not a copy of it." "The correspondence between the world and the optical image need not be that between a thing and its copy; it need only be that between a material quality and its correlate."

Now, referring to the experiment, consider that the pilot accepts whatever information is provided on the world in which he is flying. He subjects this to a correlation process which results in an internal model of this world. He then bases his performance on this internal model. Thus, as long as the simulation results in the same output from this correlation process, performance will be the same, regardless of variations in details of the simulation. This would explain the results of the experiment.

MY GOSH! ARE YOU AGAINST REALISM?

Heck no! Not only does increased realism make the scene look much prettier, it significantly reduces distracting effects which remind a trainee he is really in a simulator. Further, improvements in realism, properly used, will inevitably improve training effectiveness. The point of this discussion is that this is an extremely complex area of consideration, not at all the simple, black and white situation it is frequently considered. Full consideration of all areas is necessary both in deciding on efforts to increase available realism, and in deciding just how best to use this realism when it is available.

We are all for realism. We were the first to deliver solid-object CGI, as compared with earlier wire-figure simulations. We developed the extremely realistic fog and haze simulation now found in all CGI systems. We did not come up with the concept embodied in the curvature simulation algorithm, but we were the first to have it operational in a real-time system. We have continually improved realism by implementing measures to eliminate edge steps and other distracting quantization effects. Variable sunshading, aerial perspective, moving models, bomb-burst indication - there's a long list. But, you might ask as in the punch line of the old joke - "What have you done for me lately?"

Figure 6, produced on our laboratory scene generation system, illustrates some of the new realism-enhancement features currently being designed into real-time systems. Circular, spherical, and ellipsoidal features are used to make clouds, trees, water towers, etc. These are quite significant. Development of efficient techniques for

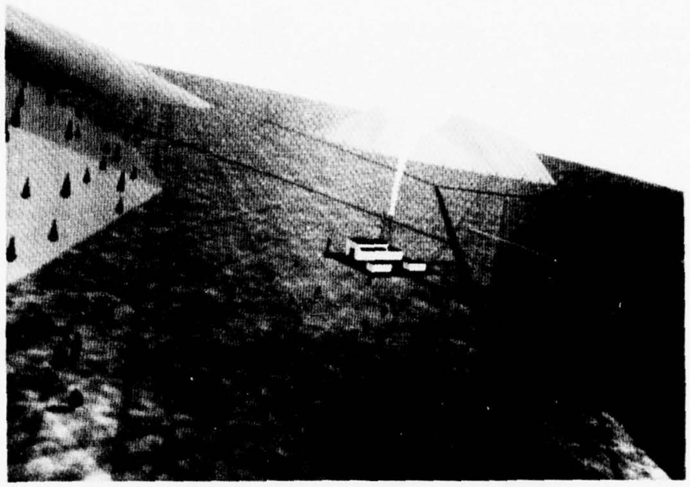

Figure 6. Scene with Ellipsoidal Features and Texture

producing these broke CGI free of its earlier straight line constraint. In many applications, a single circular feature can replace many edges.

The relation between objects and their shadows provides very sensitive motion and orientation cues. This figure shows circular features used for shadow simulation. The real-time shadow generator currently under development will use both circular features and edges, as appropriate, for shadow simulation.

On the ground, this figure shows the newly developed surface-map texture. It combines two sources of stimulus gradient information – texture gradient and parallel-line gradient. Before-and-after scenes show it to be tremendously effective in orienting all other scene features properly relative to one another.

Of course, systems currently being designed will also incorporate quantitative increases in the edges, faces, moving objects, and other elements traditionally applied to generate visual cues for training.

WHAT'S NEXT?

We are looking into several new areas now, that we are not even talking about yet. In all cases, we are attempting to apply the principles discussed in this paper to assure that we do not go after realism for the sake of realism, but that we achieve advances where they are most needed, and where the results can most cost effectively contribute to the training missions with which the systems will be used.

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ABOUT THE AUTHOR

DR. W. MARVIN BUNKER is presently a Consulting Engineer in Advanced Technologies Engineering at General Electric Company in Daytona Beach, Florida. He is currently active in research and development on conceptual, mathematical, and hardware aspects of simulation systems. This applies to perspective display systems such as electro-optical viewing systems, visual display systems, and radar display simulation. He has taught engineering and mathematics at several universities and is a member of the Board of Visitors of Embry-Riddle Aeronautical University. He received a B.S.E.E. degree from the University of Oklahoma, and an M.E. and Ph.D. in electrical engineering from the University of Florida. Dr. Bunker has authored papers in the areas of simulation, instrumentation, computer techniques, and circuit theory.

TRAINING EVALUATION OF THE HITMORE SYSTEM

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INTRODUCTION

Recent advances in the state-of-the-art in video cameras employing all solid-state charge coupled device (CCD) technology have prompted a re-evaluation of current training techniques and devices. This paper discusses the evaluation of this new technology in a training environment.

The Fairchild TOW Helicopter Installed Television Monitor & Recorder (HITMORE) was developed to provide a capability for real-time monitoring and assessment of gunner performance and immediate post-mission playback and analysis of gunner-aim point during live or simulated firings of the TOW Weapon System.

In this helicopter application, the gunner, located in the front seat of the AN-IS TOW COBRA, utilizes a stabilized Telescopic Sight Unit (TSU) with which he can detect and accurately track a target. As an aid to gunner training, and for effectiveness evaluation, provisions for a 16mm film gun camera form a part of the TSU. Training benefits of this film record are minimal because of the several day delay between exposure and screening of the film due to film processing requirements. Additionally, light level variations limit the usefulness of film cameras. Another training aid, the Gunner Accuracy Control Panel (GACP) displays azimuth and elevation gunner errors to the instructor-pilot (IP) in the second seat of the helicopter, but this system is usable only with specially conditioned targets.

HITMORE was developed to overcome these shortcomings by providing the instructor-pilot with a real-time image of gunner's field-of-view, including the TSU reticle, on a high brightness video monitor. In a training exercise, the IP can observe and verbally correct the way in which the gunner sights on the target and maintains position from initial acquisition to impact. Tracking errors and jitter in azimuth or elevation can be observed dynamically and corrected instantaneously.

For immediate detailed review of gunner performance upon return to base, the on-board video tape recorder (VTR) can be utilized. The video tape cassette, removed upon landing, can be replayed on a VTR and displayed on a video monitor for performance review, assessment and correction; this procedure can take place much more rapidly than in the case of 16mm film and therefore represents a significant training aid improvement for the IP and student. Relative advantages of the HITMORE are summarized in Table 1.

TABLE 1
VIDEO TRAINING BENEFITS

- No Target Conditioning Required
- Real-Time IP Observation/Verbal Queing
- Immediate VTR Playback on Landing
- 40 Simulated Firings on a Single Cassette
- Reusable Tape Cuts Cost Over Film
- Short Term Record to Demonstrate Improvements
- Modular Growth
- Operation Value
  - RECCE
  - Damage Assessment
  - Landing Air

HITMORE CAMERA SYSTEM DESIGN

The Fairchild HITMORE is made possible by the recent availability of small rugged low-light level TV cameras, high brightness monitors, and video tape recorders ruggedized for use in the helicopter environment. The smallest, most rugged and reliable TV cameras available employ a solid-state imaging device rather than a vidicon tube. Fairchild has developed solid-state charge coupled device (CCD) area imaging arrays and cameras which are ideally suited to this requirement. Operation at the low light levels available from the TSU beam splitter is possible because of the superior CCD sensitivity.

The CCD camera is mounted in a special bracket which maintains the same TSU interface as the previous film camera and receives information from an optical beamsplitter within the sight. The dynamic range and AGC characteristics of the CCD camera permit effective operation over a wide range of scene brightness without exposure control. This provides a state-of-the-art system with high reliability at a modest cost.

The HITMORE camera is depicted in Figure 1. The CCD camera output feeds both a video tape recorder and high brightness monitor. HITMORE Power is switched manually via a remote switching and control panel conveniently located for operation by the IP. Automatic tape recorder shut-off is provided with a manual override as a tape saving feature and assures that the recorder is not inadvertently left in a RECORD mode for extended periods. A warning light indicates end of tape.

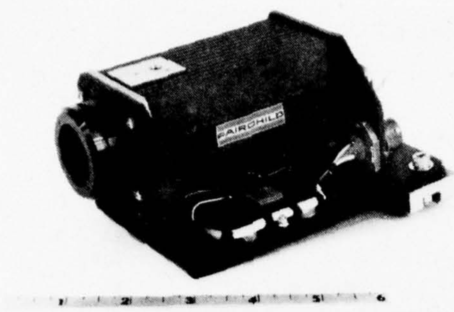

FIGURE 1. THE HITMORE CAMERA

The CCD television camera was designed to assure that mechanical and optical interface is maintained without modification to the TSU. Locating the small CCD format (7.2mm diagonal) in the 16mm film image place (12.6mm diagonal) reduces the displaced field-of-view to 57%. This provides improved target resolution and image magnification and enhances the instructor's ability to assess gunner accuracy at the projected time of target intercept.

VIDEO TAPE RECORDER AND MONITOR INSTALLATION

A High Brightness Video Monitor is mounted on the top of the gunners seatback for viewing by the instructor-pilot (Figure 2). The small size of the display serves to minimize obstruction of the IP's forward view in this location, and the increased visibility offered by use of the television camera more than compensates for the area blocked by the monitor. The video tape recorder also depicted in Figure 2 is located in the space immediately behind the pilot's seat.

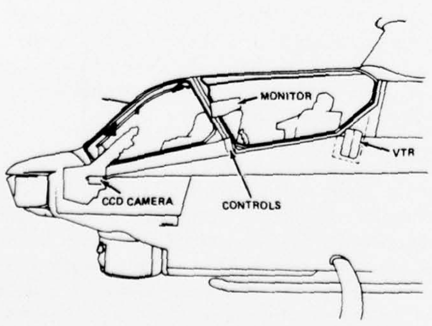

FIGURE 2. HITMORE IN AH-1S HELICOPTER

FIELD EVALUATION

In May 1978 three (3) HITMORE systems were installed at Fort Campbell, Kentucky and in July 1978, another three (3) systems were installed in Germany. Installations were accomplished at both sites just prior to extensive maneuvers and exercises with the TOW missile. Before the exercises commenced, a field questionnaire (Appendix 1) was distributed for completion by both procurement and user type personnel. Although this paper is being written prior to receipt and tabulation of all questionnaires, a number of salient evaluation factors have surfaced:

1) TRAINING EFFECTIVITY

Training effectivity was defined as the probability of a first round hit after training with HITMORE as compared to the probability of a first round hit with no training. It was estimated that this probability improved from approximately 75% to better than 95% with the use ofHITMORE.

2) TACTICAL VALUE

Instructor pilots and gunners determined that targets could be acquired several seconds faster when the HITMORE system was utilized.

3) AUTOMATIC LIGHT CONTROL (ALC)

A special camera with an auto iris was supplied prior to field evaluation in Germany to determine the ALC systems value. The basic system, without ALC, requires that neutral density filters be changed to accommodate varying light conditions. It was discovered, however, that the dynamic range of the camera was sufficient to provide acceptable images throughout all the lighting conditions encountered during training without ever changing the neutral density filter. Therefore, it would seem that ALC could add complexity with little system value.

4) NIGHT COMPATABILITY

During night exercises it was determined that the control box instrument lights were not compatible with use of the AN/PVS-5 night vision goggles. The dimmer provided could not reduce the light output sufficiently to prevent pilot blinding. The alternative suggested was use of a mechanical iris in front of each light. The optimum iris setting must be determined empirically. This solution, if satisfactory, will be incorporated in subsequent HITMORE systems.

CONCLUSIONS

- The HITMORE system has positive training value
- The tactical value of HITMORE should be further investigated
- Some minor design modifications are advisable

FIELD QUESTIONNAIRE

on

The Military Training Potential of the Helicopter Installed Television Monitor and Recorder (HITMORE)

Prepared by

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Training Analysis and Design
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US Army Aviation Center
Fort Rucker, Alabama 36362

June 1978

USER DATA: Please complete the following informational summary before proceeding to the next page.

- Unit: ______________________

- Location: ______________________________

- Date completed: ________________________

- Duty Position: _________________________

- Cobra/TOW Experience (Years) _______________

- Previous Experience with similar system: Yes _____ No _____

  (If yes was checked complete the following)

  Where _________________________

  When (Dates) ___________________

  Type System ____________________

- Experience with HITMORE (hours) _________

- Please state briefly how the HITMORE System will affect your particular job if introduced as a permanent AH-1 Cobra/TOW training aid.

HITMORE User Evaluation Questionnaire

1.0 Purpose:

This instrument is specifically tailored to collect information relevant to the operational and functional characteristics of the Helicopter Installed Television Monitor and Recorder (HITMORE) System.

2.0 Scope:

User responses are keyed to those operational and functional areas which will be most frequently encountered by the AH-1 Cobra/TOW crew and supporting AVUM/AVIM personnel. Comments on the Technical Specifications of the system are not specifically called for, but would be welcomed nonetheless, to the extent deemed appropriate by the respondent. However, should recommendations include information which most probably will result in system modification and/or redesign, it is requested that supporting drawings, photographs, etc; be submitted with a narrative description of the recommended changes.

3.0 Uses:

The information received from this questionnaire will be used in future development/procurement/evaluation decisions on the HITMORE System. Therefore, it is imperative that each respondent remain as objective as possible in evaluating the system.

4.0 General Instructions:

4.1 This questionnaire is divided into four sections. Section I is an evaluation of the contractors performance as relates to the requirements outlined in contract DAAK50-78-C-0003(P6D). Section II rates the performance of each component of the HITMORE System both individually and collectively. The Third Section is an assessment of the military utility of the HITMORE System as viewed by both the operating crew and support personnel. Section IV is reserved for open-ended discussion of future design and/or applications of the HITMORE System. There is no restriction to the length or scope of the comments the respondent may wish to include in this section. In addition to written comments; drawings, photographs, sketches, etc., are encouraged.

4.2.1 Section I will be completed by the contracting officer/ assistant contracting officer following receipt and acceptance inspection of HITMORE System(s).

4.2.2 Sections II, III, and IV will be completed by user personnel during and after system installation/evaluation.

SECTION I

Contractor Performance

	Yes	No	Remarks
- Systems were developed IAW contract specifications?	___	___	
- Functional checks met established operational criteria?	___	___	
- Systems design met stated Government standards?	___	___	
- Systems were delivered on schedule?	___	___	
- Contractor met all performance requirements of contract agreement?	___	___	
- System was developed within initial cost estimate?	___	___	
- Contractor was responsive to government's needs throughout system development?	___	___	
- Contractor fulfilled field support requirements IAW contractual agreement?	___	___	
- Contractor has prepared adequate documentation to support reliability, availability, maintainability predictions for each component of HITMORE System?	___	___	

SECTION II

Equipment Performance

	Yes	No	Remarks
- Each component functional as expected (Bench)?	___	___	
- System function was as expected (Bench)?	___	___	
- System installation was accomplished without incident or unnecessary delay?	___	___	
- System functional as expected (Aircraft)?	___	___	
- System overall performance met expected standards?	___	___	
- System is within AVUM level capability?	___	___	
- System must be maintained at AVIM level?	___	___	
- System installation/operation instruction manual is easily understood by user personnel?	___	___	
- System installation/operation instruction manual adequately describes HITMORE System operation/function?	___	___	

SECTION III

Military Utility

	Yes	No	Remarks
- The HITMORE System is an adequate TOW training aid in its current configuration?	___	___	
- The TV monitor component of the HITMORE System is considered necessary?	___	___	
- The TV monitor component should be retained and moved to an alternate location to permit use of the M-73 sight assy for mixed load?	___	___	
- Relocation of the TV monitor component to the left side of the pilot's instrument panel glare shield would not adversely degrade the pilot's field of view?	___	___	
- The HITMORE System would be an equally effective TOW training aid without the TV monitor component?	___	___	
- The TV monitor component displays sufficient brightness and contrast to facilitate pilot viewing of TSU sighting in direct sunlight?	___	___	
- The TV monitor component brightness and contrast controls are well located and easily accessible to the pilot during flight?	___	___	
- Future development of the TV monitor component should include compatability with night vision goggles?	___	___	

Section III, continued

	Yes	No	Remarks
- The HITMORE System control panel is adequate in its current configuration?	___	___	
- The function lights on the system control panel are excessively bright during night operations and should incorporate a dimming rheostadt?	___	___	
- The colors assigned to each of the control panel functions are acceptable and should not be changed?	___	___	
- The automatic record and manual override features of the control panel are both necessary?	___	___	
- Both the 30 and 60 second record selections on the control panel are considered necessary?	___	___	
- All switches on the control panel are readily accessible and easily operated by the pilot during flight?	___	___	
- The internal playback feature of the video tape component should be within the capability of the pilot for immediate film replay during flight?	___	___	
- The location and mounting of the videc tape component are acceptable from the standpoint of operation and pilot convenience?	___	___	

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Section III, continued

	Yes	No	Remarks
- The "voice-over" recording/playback capability are necessary features of the video tape component?	___	___	
- The capability for transferring control of the video tape component from the pilot to the gunner station should be incorporated into the pilots HITMORE System control panel?	___	___	

SECTION IV

Respondent Comments

(Attach drawings, photos, sketches, etc., as necessary)

1.

2.

3.

ABOUT THE AUTHORS

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OPTIMIZING MEDIA SELECTION

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and
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This paper presents a procedure for optimizing the selection of study session and device session media up to but not including life cycle costing. The procedure is presented as a detailed sketch, rather than a complete guide to the process, since the process must be adjusted to fit individual situations.

Media selection involves three components: (a) determination of media requirements for each objective, (b) analysis of the requirements for individual objectives into optimized mixes of training media, and (c) selection of a final mix based upon cost and availability. This paper presents a number of steps to accomplish the first two components. The steps are flowcharted in Figure 1.

Objectives follow different paths after they are sorted into study session and device session (hands-on) types. Study session objectives are evaluated for special requirements like audio or motion portrayal, and all media which satisfy those requirements are listed. A set of alternate study session media plans is then prepared, with each plan giving priority to some media over others. For each plan, in turn, the highest priority medium which satisfies the special requirements for each objective is selected. The number of objectives for each medium is then totalled for each plan, and any adjustments caused by overemphasizing one medium are made. Device session objectives are classified by their instructional presentation/response requirements and then by the particular hardware/software requirements of the device being trained. Objectives are consolidated to yield descriptions of trainers. The outcome of the present procedure is a list of training devices which is optimized for the particular set of objectives being analyzed.

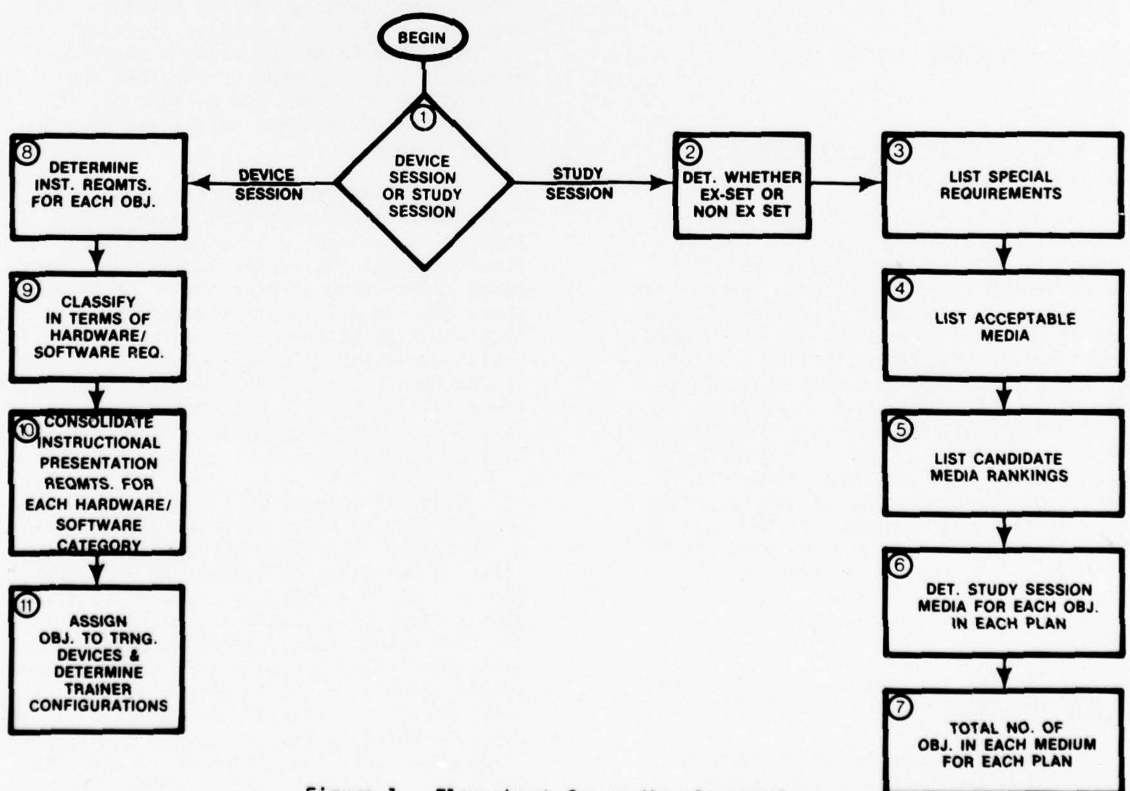

Figure 1. Flow chart for media alternatives

Each step will now be described in more detail.

STEP 1

Sort objectives into study session or device session types

The first major activity in the media selection process (Step 1) is to sort objectives into two groups: those which are study session type objectives, and those which should be presented in a "hands-on" device session exercise. Objectives are sorted because a different process is applied to the objective, depending upon which category it is in.

Study session objectives are those like stating a fact or steps of a procedure, which require self-study materials, or do not require major devices. Study session objectives may require additional materials (e.g., logs, charts, calculators, or protractors). So long as these additional materials can be stored and issued from the learning center, the objectives should be considered of the study session type. Objectives which require a particular spatial layout, tactile sensations, or movement, or which require a device which cannot easily be used in a learning center are classified as hands-on.

Study Session Media

STEP 2

Designate objectives as example-set or non-example set types

The next step for study session objectives (Step 2) is to determine whether the objective is an example-set objective or a non-example set objective. Example-set objectives are those which require multiple examples in order to present the full range of possibilites for the objective. A concept in which the student must classify an item, or a complicated rule which requires the student to use many types of inputs are example-set objectives. On the other hand, facts or procedures which are always performed the same way may be taught by presentation of a single statement of the fact or procedure (perhaps with a clarifying figure or illustration) and do not require an example set.

STEP 3

Identfy special requirements for Study Session objectives

In Step 3, special requirements are noted. These may include audio, color, visual motion, manipulation of two dimensional simulated hardware, direct instructor evaluation, automated right-wrong scoring, and high rate of revision.

Objectives which require an audio component are those based upon aural discrimination or identification such as recognizing a particular missile warning tone or voice communication. Audio, like other special requirements, should be specified only if it is essential to the performance of the objective.

"Nice-to-have" characteristics should not be specified at this point. Color should be specified as an instructional requirement only when the learner must make a discrimination or identification based upon color. Visual motion (e.g., film or videotape) is required when the student must evaluate or identify a motion change as such. For example, rapid changes in gauge readings or in targets which are to be tracked require visual motion.

The objective must also be evaluated in Step 3 for the special response requirement of manipulating hardware controls as represented on a flat screen or picture. That is, a student may be required to push buttons, read dials or flip switches where the fidelity of the system is less important than the location and sequence of the actions. For example, setting up a complex piece of equipment may be taught using a computer-driven cathode-ray tube to simulate the face of the equipment and a light pen for the student to indicate switch settings and button pushes.

Special response detection and evaluation requirements must also be specified in Step 3. Occasionally an objective will require direct instructor evaluation. Automated right-wrong scoring should be used where the student requires immediate feedback about an action which can be relatively easily evaluated. For example, the student may be required to solve a series of problems where partial answers must be evaluated before the student progresses to the next portion of the problem.

Expected rate of revision must also be specified since media have differing ease of revision. For example, very frequently changing material may best be delivered by lectures or on a computer-assisted instruction system (CAI), where a single change to the disk automatically produces changed copies each time the material is used. More stable material might be presented by workbook, where the material may be edited, typed, proofread, pasted-up, and printed. Slide tapes and video tapes are usually the least appropriate media for rapidly changing material.

STEP 4

List acceptable media for each Study Session objective

Once the special requirements of each objective have been identified, they are compared to the capabilities of already known and existing study session presentation media (Step 3). The result of the comparison is a list of all study session media which can be used for presentation of the instruction for that objective. One of the outputs of this matching of objective requirements to media capabilities may be the identification of some objectives for which no existing presentation media is acceptable. New types of media or combinations of media must be identified to handle the requirements of these objectives, for which the precise characteristics have been delineated in steps 2 and 3.

Figure 2 presents a matrix of special characteristics by study session media. Figure 2 is used by placing a check beside each special required characteristic for the objective, then locating each media column which includes all special required characteristics. In this way all candidate media will be identified which can support the particular objective.

STEP 5

Rank media in alternate plans

A result of Step 4 will be a number of media which are all capable of presenting instruction for a given objective. In order to choose between media, it is necessary to rank the different media. In step 5, a number of plans for utilizing media are developed based on alternate media rankings. Figure 3 presents a sample media ranking.

SPECIAL CHARACTERISTICS	Workbook	Workbook with color photographs	Lecture &wkst.	Lecture & wkst. & overhead sessions	Lecture & wkst. & and audio tape	Lecture & wkst. & slides & tape	Lecture & wkst. & VT	Lecture & wkst. & model	Audio tape & wkst.	Slides & wkst.	Slides & audio tape & wkst.	Random access slides & wkst.	Videotape & wkst.	Film & wkst.	CAI	CAI & wskt.	CAI & wkst. & VT
Audio					●	●	●		●		●		●	●	4	4	●
Color graphics		●		●		●	●			●	●	●	●	●	4	●	●
Visual motion							●						●	●	4		●
Manipulate hardware (2-D)								3							●	●	●
Direct instructor observation	1	1	●	●	●	●	●	●	1	1	1	1	1	1	1	1	1
Automated right/wrong scoring	2	2	2	2	2	2	2	2	2	2	2	2	2	2	●	●	●
Example set	●	●	●	●	●	●	●	●				●			●	●	●
High Revision Rate			●	●											●	●	

NOTES TO MATRIX

1. Direct instructor observation can be available in these media. However, this implies an additional resource requirement not normally associated with these media.

2. While an automated response detection and evaluation system is not normally present with these media, it is possible to add this capability. However, this addition in capability requires an increase in the resources needed to support the medium.

3. This capability depends on the characterisitcs of the model used.

4. Whether or not a CAI system has these display capabilities is highly dependent on the characteristics of the CAI system. As a general rule these characteristics are NOT normally available.

Figure 2. Matrix of Special Characteristics by study session media

Study Session Media Ranking A

MEDIUM	CEILING PERCENTAGE
1. Workbook	(70%)
2. Workbook with color photographs	(70%)
3. Audiotape with worksheet	(50%)
4. Slides and worksheet	(50%)
5. Random access slides and worksheet	(50%)
6. Slides, audiotape, and worksheet	(50%)
7. Videotape and worksheet	(25%)

An automated test-scoring and recording device will also be included in this plan to handle record-keeping requirements.

Figure 3. Sample Media Ranking

Each medium which is a candidate is listed in priority, so that an objective which can be satisfied by several media will be assigned to the medium of highest priority. In addition, an arbitrary ceiling percentage is established for each medium within the mix so that one medium (like workbook) is not assigned too large a percentage of the objectives to achieve high effect.

The rankings should be based upon present availability of media, estimated cost, need for central control, abilities and preferences of the target audience and the rapidity and extent of revisions. If the client has a variety of good equipment available (e.g., word processors, drafting tables, stat camera, printing press, slide facilities, TV studio), one of the alternate media mixes should maximize use of present equipment. One mix should minimize estimated front-end costs. The costing must be rough at this stage but can involve acquisition of production equipment, or for example, an expensive CAI system. Another mix may emphasize centralized control using CAI and minimize lectures which tend quickly to become non-standardized. Yet another mix may optimize ease of revision using lectures and CAI while severely limiting videotapes.

The developer must also consider student ability and effect. For example, students with a low-reading level should not be given large amounts of workbooks. The developer must consider how students will feel if a large portion of the study session instruction is in workbook or any one medium, and limit the total percentage for each medium in the mix (this applies primarily to the high-priority media in each mix).

STEP 6

Determine study session media for each objective for each plan

Once the media mixes have been established, they can be used along with the list of acceptable study session media for each objective to determine the study session medium, since each mix lists the media by priority.

STEP 7

Total number of objectives in each medium for each plan

Step 7 totals the number of objectives presented in each medium for each media plan.

If the total for any medium is greater than its allotted percentage, the developer must decide whether to accept the overage, to add effective elements (like cartoons to workbooks), or to reassign objectives. Reassignment can be based, for example, on selecting lessons which are likely to be revised frequently and presenting them in lectures, or selecting lessons which do not require color but would be enhanced by it and presenting them on slide/tape.

Choice between alternative plans can be based upon management factors like cost, need to accomplish rapid revisions and need for central control. Each media mix includes every study session objective, with a justification for the objective's assignment to a given medium.

Device Session Media

The procedure used to specify device session devices is different from that used for study session media, because device sessions must usually model a specific device and, therefore, the devices must be designed from scratch rather than using off-the-shelf systems like video tapes or slide tapes. Study session materials usually are relatively independent of the particular equipment being trained: A slide tape can present the procedures used to preflight any number of a set of pieces of gear, while a device session requires much greater fidelity to the individual pieces of equipment.

STEP 8

Determine instructional presentation requirements for each "device session" objective.

Those objectives which were identified in Step 1 as requiring a hands-on exercise are examined during Step 8 to determine their instructional presentation

requirements. The worksheet shown in Figure 4 can be used to record the information for each objective. The types of devices should be specified in advance. Possible device types are:

A. Schematic representation (e.g., of system flow) with line drawings, photos, or visual motion but not in proper spatial orientation.

B. Schematic representation with tactile sensation, manipulation of hardware, and real-time interaction.

C. Two-dimensional static display with the same spatial layout as actual equipment.

CATEGORIES (INPUT)	DEVICE TYPES (OUTPUT)									
	A	B	C	D	E	F	G	H	I	J
Audio							●	●	●	●
Visual motion	●	●				●	●	●	●	●
Tactile sensations		●		●	●	●	●	●	●	●
Spatial layout			●	●	●	●	●	●	●	●
Movement sensations									●	●
Manipulate hardware (3D)		●			●	●	●	●	●	●
Direct instructor observation	●	●		●	●	●	●	●	●	●
Delayed instructor evaluation & scoring							●	●	●	●
Automated right/wrong scoring	●	●				●	●	●	●	●
Automated tolerance data collection							●	●	●	●
Branch to new display		●				●	●	●	●	●
Real time interaction		●				●	●	●	●	●
Performance playback								●		●

Figure 4. Matrix of Characteristics of Device Sessions Types

J. Simulator with motion base and performance playback.

STEP 9

Classify each "device session" objective in terms of its hardware/software system capability requirements.

In addition to classifying each hands-on objective in terms of its instructional presentation requirements, it is also necessary that each be classified in terms of its hardware/software system capability requirements. This is important since hands-on devices are often expensive to develop and costly to operate. For this reason, the training devices must possess the right combination of instructional and hardware/software capabilities to allow for maximum utilization of the devices, accomplishment of all objectives, and minimum development and operating costs. The procedure presented in this step is not algorithmic, in that it results in one correct answer which satisfies all of the above criteria. It is analytic in that it allows for systematically examining the variables which go into determining the "optimal solution." The final grouping of requirements and identification of a trainer suite should be based on the results of this procedure together with knowledge of cost and availability of present trainers. For example, it may be less expensive to modify an existing complex device or to stimulate the actual equipment than to design and build a less complex device. Moreover, it may be less expensive to design and build two copies of a complex device than to design and build two separate devices, one which is complex and another which is simpler.

In order to determine hardware and software requirements, a table is constructed which lists the course objectives down the side and hardware/software systems and subsystems across the top. Figure 5 presents an example of a small portion of such a table. The proper column headers can be identified using the following procedure:

First, for each training track, each hardware/software component directly utilized, inspected, or serviced in a hands-on mode is listed. Components directly utilized or manipulated by the person are included as well as integrated components at the level of detail normally utilized on the job. For example, integrated panels rather than single switches are included for a pilot.

Following the list of single components above, all hardware combinations commonly utilized simultaneously can be listed. An example for a pilot of two hardware systems commonly used simultaneously is the Head-Up Display (HUD) and the Flight Control System. First, list all pairs, then all triples (e.g., the HUD, Flight Control System, and communication panels), then all four types, etc., until all common combinations have been enumerated. If several people work as a team, include all equipment required by the team.

Once this table has been constructed for all training tracks, the hardware/software system requirements can be identified. To do this, for each objective find the simple column which represents the mix of hardware and software systems and subsystems needed to adequately perform the objective. If no column corresponds to the necessary hardware and software requirements, then a new column should be added to the table. Once the appropriate column has been found, the letter of the acceptable device presentation/response type is entered in that box. For example, in Figure 5, objective 1.2.2 requires the Flight Control System (FCS). The letter of the device presentation/response type (Type A) is written in the intersection of objective 1.2.2 by FCS. Only one column is used for each objective.

Objective	Component					
	HUD	Flt. Control Sys (FCS)	Comm	ECM	HUD-FCS	HUD FCS Comm
	1	2	3	4	5	6
1						F
1.1	D					
1.1.1	D					
1.2		H				
1.2.1		G				
1.2.2		A				
2					F	
2.1					E	
2.2					E	
2.2.1					A	
2.2.1.1.					A	
2.2.1.2					A	
3			C			
3.1			A			
Consolidation						

Figure 5. Sample table of objectives by hardware/software components

STEP 10

<u>Consolidate instructional presentation requirements for each trainer hardware/software systems-requirements category.</u>

The objectives must be grouped in some systematic way in order to arrive at an optimal set of trainer descriptions. The first step in this consolidation process is to determine the presentation/response type which is adequate for all objectives with each given hardware/software system (i.e., columns in Figure 5).

Usually complex devices can accommodate the presentation/response requirements of objectives assigned to simpler devices. Therefore, each hardware/software column is scanned to find the one or possibly two most complex devices, and all objectives in the column are assigned to the complex device. This is done since the device must be constructed in any event to satisfy an objective, and it should be used to its maximum.

STEP 11

<u>Assign objectives to training devices and determine final trainer configurations.</u>

a. Identify hardware/software system requirements of most complex trainer.

In relative terms, the training device which is most expensive to develop and operate is the device which is most critical to use properly. Therefore, the hardware and software requirements of the most complex

device should be determined first to allow maximum flexibility in the assignment of objectives to that device. This is done by examining the training device requirements table which has been consolidated with a column, and identifying the column or columns which contain the largest number of hardware/ software (H/S) system requirements.

The instructional presentation/response requirements for that set of H/S system requirements was determined in step 9 and consolidated in step 10.

These two sets of requirements serve as the basis for characterizing the capabilities of the most complex training device. Using this information, a tentative description of the training device is developed to outline the proposed capabilities and features of the device.

b. Estimate trainer time available for each student on the most complex trainer.

Having tentatively specified the required characteristics of the most complex trainer, it is possible to identify hands-on objectives which can be accomplished by using that trainer. However, prior to beginning this, a question which must first be answered is: How many objectives can be assigned to the trainer to fill (but not overfill) the time available on it? A formula to compute time available for each trainer has been developed. Essentially it multiplies number of days in the training program by hours available per day, then divides by number of students. Corrections are made for anticipated downtime and proportion of day used.

c. Assign objectives to the trainer until all available trainer time has been used up.

Once steps a and b have been completed, it is possible to begin making a fairly firm assignment of objectives to the device. To ensure that the most appropriate objectives are assigned to the device, the following priorities may be used.

PRIORITY I

Objectives which require the full range of both the instructional presentation and response (P/R) capabilities, and the H/S system capabilities of the trainer device.

PRIORITY II

Objectives which will require the full range of the H/S system capabilities but less than the full range of P/R capabilities.

PRIORITY III

Objectives which will require somewhat less than the full range of H/S system capabilities but the full range of the P/R capabilities.

PRIORITY IV

Objectives which will require less than the full range of both the P/R capabilities and the H/S system capabilities.

All objectives in Priority I class should be assigned prior to assigning any objectives in Priority II class. When choosing between objectives within priority classes, those objectives which come closest to using the full range of capabilities should be assigned first. When choosing between objectives in Priority IV class, the H/S system requirements should be the controlling factor for assigning ojbectives.

d. Repeat trainer requirements determination and objectives assignment process for each required trainer.

Once the requirements have been determined for the most complex trainer and objectives have been assigned to it, the process outlined in steps a, b, and c can be repeated with the remaining hands-on objectives for the next most complicated trainer. The process should be repeated again and again until all trainers have been identified and all objectives have been assigned.

At this point, it is useful to examine the entire set of trainer assignments. The procedure recommended in this approach will result in all trainers, except the last of each type, having enough objectives assigned to them to fill all available time. For this reason, the trainer assignments should be examined to see if some minor shifts can be made in the assignments to equalize the usage levels.

e. Develop detailed description of each trainer.

Once satisfactory assignment of objectives to trainers has been reached, it is necessary to prepare a more detailed specification of the required capabilities of each training device. The instructional presentation capabilities and the hardware/ software capabilities should be specified in detail. These descriptions should be sufficiently complete so that they can serve as input to the development of the trainer functional specifications.

Following this process, it is necessary to develop a detailed set of functional specifications and detailed costing and support-requirements estimates for each proposed trainer. These steps need to be worked out with manufacturers of the equipment.

ABOUT THE AUTHORS

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COMPUTROL COMPUTER GENERATED
DAY/DUSK/NIGHT IMAGE DISPLAY

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INTRODUCTION

Advanced Technology Systems (ATS), welcomes this opportunity to describe our advanced computer generated, full-color, day/dusk/night Simulator Visual System which we call COMPUTROL*. We believe that the system represents a genuine breakthrough in the state of the art, in that the level of picture detail far exceeds that of currently available systems.

Among the noteworthy features of the ATS system are:

Its ability to produce a full-color, day/dusk/night picture including blue lights. A minimum of 10,000 colored point light sources can be generated and displayed.

Its ease of generating a new picture. A new airport can be programmed in one working day.

Its ability to display 30,000 edges. Expansion to 100K edges possible.

Its ability to drive additional, independently controlled displays.

Realistic special effects such as horizon glow, variable cloud cover, variable visibility, correct sun angle, moving traffic and lights whose intensity varies in slant range.

No blooming of lights at the end of runway.

As will be discussed later, the technology to produce a high-definition picture with full-color, smoothly rounded curves and infinite shading has been developed with illustrative photographs to prove the point. Color shading has also been developed for transition of one color to another without abrupt or noticeable effects.

BACKGROUND

For those not acquainted with ATS, please permit a slight digression. We are an operating division of The Austin Company, an organization of engineers, designers, and builders established in 1878 and operating coast-to-coast in the U.S. and 12 international offices.

ATS was organized as the Special Devices Division to handle classified research and development projects and has been devoted to the advancement of the state of the art of visual simulation since its founding in 1943.

Our credits include:

A torpedo and rocket attack trainer which features the first spherical-domed visual system of the simulated world environment in which the trainee maneuvered (12 units built).

Every Submarine Periscope Training System used by the U.S. Navy. Many now include our 40:1 diffraction limited zoom lens which revolutionized the Submarine Periscope View Simulator performance.

EARLY CGI DEVELOPMENTS

Our first Computer Image Generator was a nighttime system for the simulation of harbor navigation. ATS designed and developed a color, nighttime, dynamic CGI system which provided a 360^{o} view capability with simulated own ship speeds up to 60 knots. The system had 300 point lights, some of which were hooded to permit viewing to a restricted FOV. The simulated buoy lights blink at controllable rates which permits the maneuver into and out of a simulated harbor.

This early system also simulated aircraft flight providing maneuverability for takeoff, landing, and airborne maneuvers. Recognizing the inadequacies of current daytime CGI techniques, ATS embarked upon the development of the COMPUTROL Day/Dusk/Night Image Display and Control System.

The goal of this developemnt was increased capability for the real-time manipulation of perspective views of three-dimensional objects. The resulting system design will be capable of generating enhanced detail for terrain, cultural features, and moving target models while also displaying such special effects as contrails, weapon impacts, and transparencies.

* Registered Trademark

Upon becoming acquainted with the accomplishments of the Human Resources Research Organization's (HumRRO) CHARGE System, the two organizations decided to combine technical and financial resources for the fulfillment of common goals.

The CHARGE (Color Half-tone ARea Graphics Environment) System, part of a HumRRO study conducted in 1971 and 1972, addressed Computer Aided Instruction (CAI) techniques. The purpose was to develop specifications for a total CAI system with components that included hardware, software, lesson plans, and instructional decision models.

Image generation techniques were first modeled in software so that alternative algorithms and hardware architecture could be studied, simulated, and verified before committing image generation functions to hardware. The resultant hardware/software design exceeded expectations, rivaling in sophistication and performance any CGI system then on the market.

As a result of a continuing effort in the study of image generation techniques, ATS/HumRRO has evolved the basis for the current advanced design. While committing certain image generation functions to hardware to achieve an order of magnitude increase in processing capability, the system still retains immense versatility both in hardware and software flexibility. The main advantage is that it can handle more edges in real-time at less cost. Any additional or new image generation algorithms can be incorporated since algorithms are not completely frozen into special-purpose hardware.

APPLICATION SCENERIO

Although a CGI system can be tailored to match a variety of visual requirements, this paper relates to aircraft operations rather than other vehicles' use. We have, therefore, related our discussion to aircraft visual simulation.

The COMPUTROL visual system will present a CGI scene to the pilot which reproduces the outside world viewed through the windshield during ground handling, traffic pattern, and low-level maneuvers as well as high-altitude flight for both day and nighttime training.

With the exception of a flight data interface with the simulator host computer, the visual system is a self-contained digital image generator with bulk storage of specified geographical data bases. An off-line data base modeling capability is included.

The visual system will allow realistic training in all maneuvers, specifically:

Takeoff with critical engine failure.
ILS approach with engine failure.
Landing with engine failure.
Rejected landing.
Rejected takeoff.
Takeoff with crosswind.
Approach and landing with crosswind.
Instrument takeoff.
Nonprecision approach.

The visual scene will follow all motions computed by the simulator and, therefore, can visually reproduce any maneuver of which the simulator is capable.

DESIGN

The visual system covered by this paper consists of the following components:

Digital computer Simulator interface
Image processing hardware
Cockpit displays
Gaming area/storage retrieval system
Support Equipment (SE) and Built-in Test
Gaming area modeling equipment

The visual computer consists of a special-purpose digital processor and related equipment. Insertion of a new gaming area into core requires less than ten seconds.

BASIC SYSTEM HARDWARE CONFIGURATION

The general configuration of the COMPUTROL system consists of essentially three components: Image Generator, Memory/Decoder Units, and Disc Storage Units.

The image generator performs in real-time all functions required to generate a perspective view from a compiled world whose unspecified parameters are derived from the user's input device or from another computer.

The memory/decoder units receive from the image generator the edges representing the selected two-dimensional projection of three-dimensional objects and buffers and decodes the edges for display on the monitor screen. One or more memory/decoders can be assigned to a color montior.

The disc storage units store the 3D definition of objects and surfaces comprising the data base gaming area. This representation of the real world is logically segmented into related object sets so that a "user" may roam through a world, not all of which can be held in the image generator's main memory at once.

The image generator consists of two parallel processors: the projection processor and the visible surface processor. Each processor consists of custom designed high-speed controllers and arithmetic units which communicate with a specially designed high-speed CPU and main memory.

CPU

Initially the architecture of the CPU was designed with the intent that image generation be accomplished utilizing a high-speed CPU in combination with a high-speed arithmetic unit. Further study, however, indicated, that by putting more of the image generation work into special-purpose subsystems, an enormous increase in speed could be realized. Thus, the major workload of image generation has been moved into the special-purpose subsystems and placed under the control of the CPU. Its high-speed architecture has been retained not only to provide the speed necessary to control the arithmetic and special circuitry, but also to provide the versatility for further system growth. This growth capability accommodates further research and development by permitting the simulation of additional features.

The ability to permit host computer functions to reside in the CPU may also be accomodated. This ability may be useful to permit stand-alone applications, to relieve the host computer of its workload, or even to provide look ahead computations to enhance image generator output.

The image generation capability of COMPUTROL will:

Display up to 30K edges in any single channel or throughout a wide angle FOV. Edges may be utilized to model point light sources, ellipsoidal surfaces, etc.

Provide up to 1,000 "X" intercepts/scanline. 2K, 3K, etc. intercepts may be handled by expansion of hardware buffer size.

Within the edge capability, provide for unlimited high resolution aircraft and/or ground vehicle images.

Display point light sources (10,000 min.)

Be limited only by the mass storage device for those portions of the world outside the FOV.

The COMPUTROL system is a special-purpose design and does not use general-purpose hardware other than standard peripheral equipment such as magnetic tape or disc units. The special design includes a CPU which may be utilized to facilitate implementation of new computational algorithms and to support further CGI development.

The attached data sheet illustrates COMPUTROL's image processing capability.These photographs have been taken from a standard 15" 525 line TV monitor that has been modified by increasing the bandwidth of the video amplifiers by a factor of five and the vertical

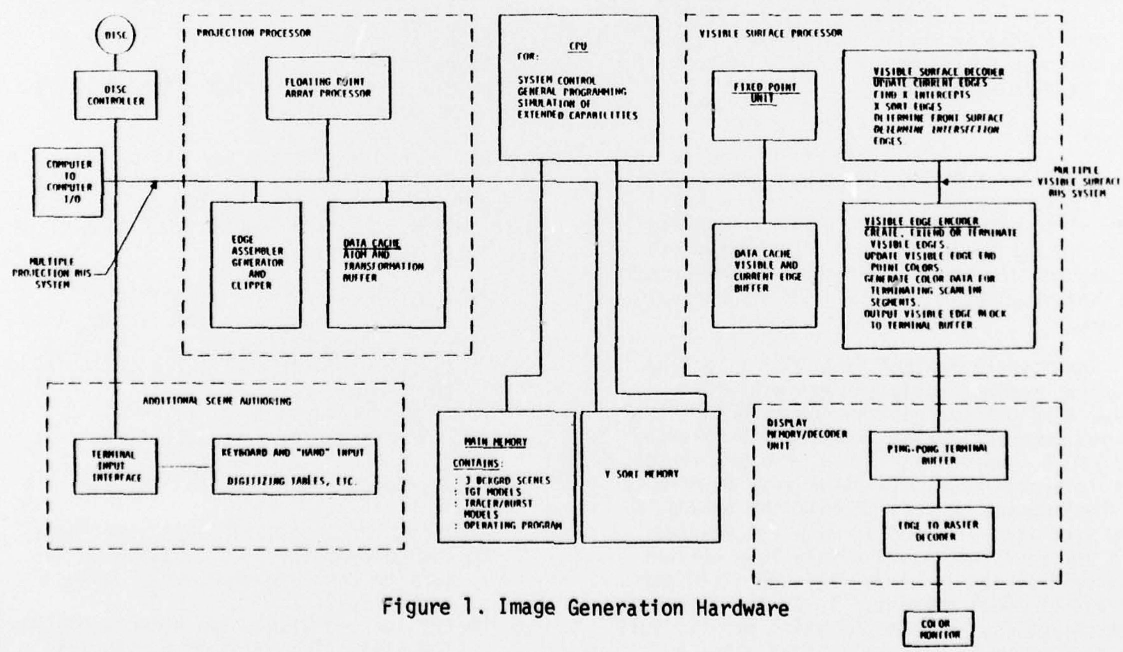

Figure 1. Image Generation Hardware

"resolution" to 1200 lines by a means of a 5:1 interlace.

Dulles terminal, as viewed from the cockpit window of a taxiing aircraft, consists of 2,162 edges.

The simulated view of a CONCORDE in the landing configuration consists of 910 edges. Color shading capability may be appreciated by a close examination of the fuselage. Motion of control surfaces (wheels, nose section, flaps, etc.) is updated in each new TV frame.

The dining room scene consists of 9,130 edges and is representative of the detail possible with the 16,000 edge early development system.

PHYSICAL CHARACTERISTICS

The CGI system, exclusive of displays and input terminal, is housed in a total of four vertical, joined cabinets suitably finished and covered. Cable access is from the rear and circuit board access is from the front.

One cabinet contains the wire-wrap logic boards for all CPU, processing, controller, cache, and interface functions required for the projection and visible surface image generators.

The second and third cabinet similar to the first houses main memory (MOS) mounted on PC cards, interconnected via edge connectors, mounted on a "mother board" chassis, and two dual-disc drives. Blowers and power displays are distributed in the fourth cabinet to support system requirements. A basic control panel is also included.

DISPLAY

The Cockpit Display System is mounted on the flight compartment/motion platform and produced a real-time, through the windshield color virtual image display. The system can include one or more high-resolution color monitors and associated infinity viewing optical systems.

The display monitor is a 1029 scan line RGB color monitor using a high-resolution shadow mask CRT such as the RCA 1908P22. The gun and phosphor design provides a brightness of 77 foot lamberts for 1 ma. of beam current. This is a high-resolution tube with 20 mils spacing between centers of adjacent triads. A very fine line width of 10 mils is obtained at a 40% amplitude level of the beam current density distribution curve for 200 micro amp per gun of anode current. It is the fine-beam spot capability of this CRT which permits full use to be made of the small triad spacing.

The selection of the RCA 1908P22 is based on its resolution, high brightness, availability, and the fact that this type has been successfully used on other beamsplitter, spherical mirror systems.

DETAILED DESIGN CAPABILITIES

COMPUTROL uses a numerically stored model and data of the real world to generate "out the window" visual scenes. All objects in the data base are modeled in three dimensions so that the observer can move about at will, throughout the playing area, with no restriction on movement, direction, altitude, or velocity.

Features of aircraft or other vehicles will be of sufficient detail to be visually identifiable at a range equal to the range in real life. As range decreases the motion of control surfaces will become visible. These surfaces will move as if they were actually controlling the motion of the aircraft.

The COMPUTROL is designed to interface with multiple terminals. The terminal screen will act as a window into a three-dimensional world containing representations of:

physical objects symbols
graphic images surfaces
physical events

The representations in this 3D world may:

be solid, liquid, or gas
have any color, brightness, sheen, transparency
have any shape
be point light sources
have any location, orientation, scaling, and magnification

All parameters in the definition of the world and all parameters in the specification of the "window" into that world may be dynamic in real-time. Allowed functions of time or of user input include:

Polynomial functions, i.e. constant velocity, constant acceleration, etc.
Analytical functions such as sine (kt), square root (kt), e^{kt}, log (kt), 1/log (kt), etc.
Numerical functions
Arbitrary space/time trajectories

Object/Objects interactions include:

Illumination shading of object surfaces
Collision dynamics (i.e., collision detection and conservation of momentum and energy)
Object lock-on (i.e., two objects colliding will stick together during and

following trajectory -- useful when one of the objects is under the control of a hand or joystick input device)

Planar scalpeling and "window" clipping (i.e., selective cross-sectioning of subsets of objects)

IMAGE GENERATION

Scenes, as displayed on the CRT, are described by the edges of surfaces. The system has the capability of displaying 30,000 edges. A minimum of 10,000 colored point light sources are available for use in the night scene.

The surfaces can be planar, cylindrical, or spherical because of the system's ability to "smooth shade" curved surfaces. The 30,000 edges is a limitation on display detail and not on gaming area complexity. There is virtually no limit to the number of edges in the gaming area data base. The computer system discards edges not visible by virtue of being out of the field of view of the pilot or ones describing hidden surfaces. Another feature of the system is the ability to select the sun angle. This will be evidenced by different sides of buildings, hills, etc. being in shadow.

As the pilot nears touchdown, his landing lights will illuminate the runway ahead of him exactly as in real life. The area illuminated by each light is computed separately to produce the correct presentation for any combination of lights being used.

The visual system will accurately depict the simulator's computer flight space with sufficient realism and definition to induce proper psychological motivation and provide capability for rigorous pilot training. It will operate with accuracy and response so as to preclude the possibility of perceptible disagreement between the visual display and other parts of the simulation, including any motion cues and instrument indications, over the entire range of specified operation. The system will permit the aircrew to determine attitude, altitude, relative attitude rates, and relative velocity by reference to terrain and horizon features in the same manner as in an actual aircraft under visual flight conditions.

Real world six-dimensional changes will be simulated in size and perspective realistically and accurately in real-time with respect to aircraft under visual flight conditions. The system will provide realistic visual simulation of the taxi, landing, and takeoff phases of flight as well as all flight maneuvers. All maneuvers will be visually current. The visual system will properly display attitude and flight path characteristics that are associated with sideslip and crabbing maneuvers during crosswind landings and general maneuvering flight.

The visual system will portray all scene landing in the field of view in their proper perspective. The scene elements will be displayed with respect to their modeled coordinates to within three arc-minutes positional accuracy as seen from the crewmember's seated position.

The visual system will track the simulator's computer flight position to within one-half foot and its computer flight attitude to within three arc-minutes for the duration of the flight. Any modeled point will be locatable to within one inch in the data base.

FUNCTIONAL OPERATION OF THE CGI SYSTEM

The author language is divided into an atom language, and an object/world language. The atom language permits the creation of "primitive" objects out of xyz data, such primitive objects being termed atoms. The object/world language permits the modification or building of more complex objects/worlds out of other objects and atoms.

Worlds, objects, and atoms, portions thereof and operations thereupon, may be given symbolic names (labels) for their construction and manipulation.

The basic library contains standard two- and three-dimensional atoms such as cubes, spheres, cylinders, wedges, circles, squares, and triangles. Special atoms are created for such items as an airplane aileron when it cannot be adequately represented by combining standard shapes. Once created, the atom is added to the library and is available for use wherever needed. The atoms are created in one or more of the following ways:

By polygon input method
By contour input method
From other sets of points by interactive and/or analytical techniques
By modification of another atom, its points, contours, etc.

Additional capabilities are techniques to warp, bend, and cut. Logical functions between atoms (volume common to two atoms defines a third atom, etc.) along with parametric specifications of an atom are also included.

Objects or worlds may be created by assembling them out of transformations of one or more objects or atoms. Allowable transformations on objects are:

Translation (move in xyz) Size scaling

Surface or point recoloring (the color within a surface is a liner interpolation from the color at the edges defining the surface)
Rotation (about xyz)

IMAGE HANDLING

An image is encoded by a set of edges. An edge is a real or an imaginary line to the right of which is displayed a color. The data word which defines an edge contains such characteristics as color, hue, saturation, brightness, and magnitude in xyz space. There are many atoms which could be described, but let us explore the cube as an example.

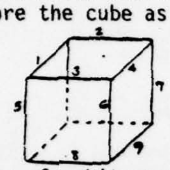

Figure 2.

A polygon of arbitrary shape and color is represented by these edges. Figure 2 depicts a perspective of a cube represented by nine edges. Because the color may vary lineraly along edges bounding the polygon and lineraly in x between edges, a polygon can also represent a portion of a curved surface. By means of these polygons, both flat and curved surfaces can be represented in any illumination environment.

When objects are occulted by other objects, new edges are created called "intersection edges." These intersection edges are created in real-time and do not reduce the basic 30K edge capability of the system. They are, therefore, not counted as additional visible edges.

We foresee that a later generation of COMPUTROL will provide the capability of computing 60K or 100K potentially visible object edges and displaying them in any single window or combination of windows throughout the FOV.

DATA INPUT

Data entry sequence is used by the modeler to create and manipulate descriptions of two- and three-dimensional objects and display real-time perspective views of these objects at his monitor. The major software components involved in managing the data are described below.

OPERATING SYSTEM

The monitor program handles all physical input/output requirements of the CGI software. These input/output devices include:

Visual display channels
Alphanumeric CGI and keyboard
Mass storage disc drives and controllers
Digitizing tablet
Card reader/punch
Operator's monitor
Printer Teletype
Link with the host computer

The mass storage discs are arranged into libraries and entries within libraries. A library is generally a logically related collection of entries such as object codes for programs, atom descriptions and compiler output listings to be printed or displayed via CRT, etc. Libraries and entries may be created, deleted, or modified either under program control or under user control via interactive commands. There is no restriction upon the number or size of libraries permitted other than the physical restriction of disc storage size. A library may contain either fixed-length data block entries for random access of variable length data.

Using the CGI system to advantage, the programmer may do such things as:

Delete an entry from a library
Delete an entire library from a disc
Copy an entry from one library to another
Copy a library of entries to another disc
Rename an entry or library
Merge two libraries together
Load a library from another medium, e.g. card reader
Copy an entry or entire library to another medium, e.g. card punch or printer
List the names of library entries, libraries on a disc or discs currently on the system.

TEXT EDITOR

The text editor allows a user to create, update and store text in a general form. Each collection of text is stored by name in a disc library and may be retrieved at any time for subsequent inspection or modification. While the text may be any arbitrary sequence of symbols in general, more specifically it will be used to contain the descriptions or atoms and objects created by a modeler. This text may be initially entered by using a keyboard and CRT terminal, by using a card reader as input or by using an interactive digitizing tablet program which generates text as its output. The modeler specified point coordinate locations and point linkages, with the program generating the modeling language statements as if the modeler had typed these statements directly. Thus, subsequent keyboard modifications to the data, such as the appending of comments of other features, are permitted, regardless of the original source of the input text.

ATOM COMPILER

The atom compiler processes a user's text description of the three-dimensional structure of an atom and generates an encoded description of the atom for subsequent processing by the image generator. The resultant compiler atom is stored by name in a disc library for later use in constructing objects. As delivered, the system library will contain a wide assortment of atoms reflecting geometric shapes and other special shapes encountered in modeling the data base. There is no limit imposed by the CGI hardware design on how many additional atoms and objects can be defined by the user. Optionally, a listing file is produced by the compiler containing the source input statements, a sorted cross-reference list of all mnemonic names used in the atom description text and error diagnostic messages if errors were encountered during compilation. This listing file may be examined on-line using the text editor, printed on a hard copy device, retained on disc for later reference or deleted from its listing library.

OBJECT COMPILER

The object compiler processes text describing a collection of previously defined atoms and objects and creates one or more new more complex objects from them. The input text identifies a set of atoms and objects by their names and specified such things as the color, size, and location of each with respect to the others. The resultant compiled object is stored by name in the specified disc library for subsequent viewing or use in constructing other objects. As with the atom compilation process, a listing may be produced by the object compiler.

WORLD COMPILER

The world compiler prepares a group of objects for processing by the image generator. A world consists of an object and a set of viewing parameters. The viewing parameters define such things as the color and brightness of the background area, the location and brightness of the sun and so forth. The world compiler is also responsible for segmenting large logically related sets of objects into "sub-worlds" and organizing linkages among these various sub-worlds so that a user may "roam" through the world, not all of which can be held in the image generator's main memory at once. The compilation process is in no way sensitive to the number of image generator channels to be used in displaying the world.

IMAGE GENERATOR CONTROL

The image generator control software controls the operation of the various image generation hardware units. It first performs parameter substitution of all numeric parameters of a given world which were left unspecified at compilation time. These parameters are supplied by the modeler's control devices or by the digital computation system, whichever is controlling the image generator. After parameter substitution, the resultant compiler world is treated as a command list which causes the image generator control program to command the individual special-purpose hardware units to transform the data list portion of the compiler world into a set of projected edges in the user's CRT screen domain. Finally, the projected edges are transformed into visible edges by commanding the arithmetic units of the visible surface processor.

The modeler user creates his world from atoms and objects as detailed in the preceeding paragraphs. He combines objects and atoms to make other objects and scenes. This is done in the coordinates of a "scratch" world so that he can monitor his progress without the distraction of other objects which might occult the object being worked on. When complete, the objects are given real world coordinates and orientation to place them properly in the playing area data base. It is also possible to remove any object from the data base to the scratch world for making modifications or corrects.

ATOM LIBRARY

The library of standard faces, objects, and models which comprise the atoms and objects of the ATS author language has been illustrated in Figure 3. The ability to generate new atoms and objects is only limited by the modeler's imagination. The various methods of constructing the basic shapes have already been described with illustrations of the variations possible shown in Figure 4.

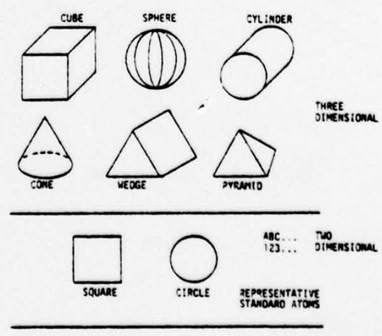

Figure 3.

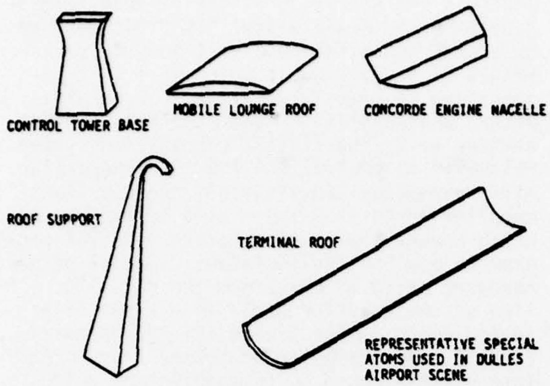

Figure 4.

These atoms were specially developed to conform to the real world atoms of the Dulles Airport complex.

In Figure 5 we model a car. A basic car "cube" atom has been extended and flattened to represent the car body. A similar atom is added to represent the top. Other modifications of the basic shape produces a car image with recognizable detail. The modifications may be refined until the car has the fidelity of an artist's rendering of a car.

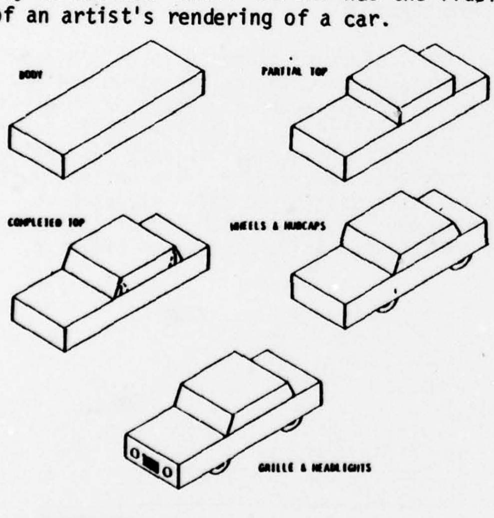

Figure 5.

TERRAIN GENERATION

We have discussed the users modeling of various objects. To place the objects into a "world" environment requires the modeling of terrain.

GENERAL TERRAIN

I/O equipment will be used to input raw data from constant elevation contours of topographical maps. Initial data reduction would be accomplished by techniques that monitor distances and radii of curvature between successive points along each contour. At this stage, color data can be introduced; a point that is not explicitly tagged with color data will be automatically assigned that color derived by interpolation as a function of its fractional distance between two points that are tagged with color information.

HIGH-RESOLUTION TERRAIN

For high-resolution (close up) modeling, the data would be passed through a software package that connects successive contours with triangular facets. The technique attempts to optimize the selection of the triangular facets by minimizing the volume of the resultant general polyhedron that is thus formed. There is no restriction that contour lines be convex.

MEDIUM-RESOLUTION TERRAIN

The same process can be used at lower resolution by further reducing the number of redundant data points along a contour and by considering fewer, more widely separated (in elevations) contours.

LOW-RESOLUTION TERRAIN

An alternative technique that could be used for relatively distant terrain would be to pass the initially reduced contour data through a software package that would perform a Fourier analysis of the surface; that is, a set of parameters would be generated that would permit the generation of a continuous analytical surface that approximates the original terrain surface. For lower resolutions, the higher Fourier coefficients would be excluded from the computation of the analytical surface.

HIGH-RESOLUTION DETAIL

The occurence of a significant geographical feature, such as an isolated mountain surrounded by relatively flat field, will be handled by creating them separately from the general terrain and placing them as objects in the gaming region.

LAKES

Lakes (regions of constant elevation) lend themselves nicely to the constant elevation contour technique since the shape of the lake

should be independent of the surrounding higher elevation terrain.

PLACEMENTS OF OBJECTS ON TERRAIN

Software will permit the modeler automatically to place objects at (x,y,) positions on the terrain. This is particularly important, for example, for the automatic placement of a 2-D type of object such as a road or a river, on top of the faces of the terrain contour.

DESIRABLE FEATURES

OCCULTATION

For any given viewpoint, the CGI system will generate the appropriate perspective between overlapping surfaces. As conflicts between overlapping surfaces are resolved, intersection edges are created for display of proper occultation relationships.

COLOR

The CGI system generates image coded in nine bits for each of the red, green, and blue channels of the TV display. This corresponds to 512 intensity levels for any color. The data base is stored by specifying for each object its color in the visible spectrum.

CURVED OBJECT SIMULATIONS

The CGI system provides realistic curved object simulation by assigning color to vertices and lineraly varying the color between the vertices and along the scanline between edge intersection. Color interpolation solutions are performed in parallel with the decoding of edges and do not affect the linear geometric processing or display capability of the image generator.

PROGRAMMABLE FIELD OF VIEW

The field of view for each of the windows is completely programmable. Thus, for any given window the FOV need not be defined as that required to completely fill the window but instead can be that FOV defined by any portion of the window. This is possible since the window/clipping parameters are programmable and can be altered or varied as described.

SYSTEM OVERLOAD

Overloads, caused by excessive edge capacity in a computed scene, is eliminated by employing frame-to-frame coherence monitoring. This type of monitoring senses the number of visible edges in a scene and utilizes this number to cause logical simplifications of the world when overload conditions are approached. Thus, if the number of visible edges in the FOV approaches the limit during a frame solution, certain objects will be simplified to assure maintaining the edge count below the maximum capable of display by the system.

If, despite the logical detection and subsequent object simplification an overload does occur, the system design is such that the solution is completed while the last solution is used to refresh the display. With this approach, an overload will not cause picture disintegration, but will merely cause a momentary and slight delay. The frame-to-frame coherence will prevent this overload condition from persisting and of course will minimize the probability of its occurrence.

POINT LIGHTS

The CGI system permits the display of a minimum of 10,000 colored point light sources. Lights can be modeled whose intensity is constant or varies in accordance with slant range and time (blinking). There are no restrictions on placement.

PERSPECTIVE LIGHTS

Perspective lights are modeled individually by the author language. Several different types of perspective lights are possible including omnidirectional, such as taxiway lights and directional, such as VASI lights. In addition, a certain number of the perspective lights can be designated as light emitting. These will emit colored light with appropriate color mixing and surface absorption as observed in a real physical environment (a blue object illumined by a red light will appear black). The directional lights are modeled with hoods such that the cone of visibility may be specified.

AERIAL PERSPECTIVE

"Aerial perspective" is an important ingredient in any visual presentation. A certain amount of visibility limited haze or fog almost always exists, so that a scene without it lack realism. It provides an additional altitude cue by causing the horizon to seem lower as the point goes higher, and is a factor in his ability to judge the range of targets within the blanket of haze. The fog blanket also provides a hiding place for ground, or low-flying targets and so is essential in combat simulation situations.

The visibility restriction is simulated as a low-lying layer of haze, fog, or smoke. It is densest at ground level and thins out with height. The operator selects thickness

of the layer as well as the density at ground level. The CGI system computes the visibility and observed color of each component of the data base as a function of the altitudes of the object and the observer, and the slant distance between them.

MOVING MODEL SIMULATION

The CGI system puts no limit on the number of items in the data base that can be dynamic. Likewise, there is no restriction on the degress of freedom of this motion. Any part of an object can be addressed separately so that incremental movements are also simple, that is, an aileron will move with the airplane but also rotates about its hinge line.

TEXTURE

To provide surfaces with a realistic textured appearance, it is necessary to display the texture pattern with the same perspective processing applied to object or polygon edges. There is, therefore, a need to obtain a perspective of each discernable "characteristic" of a texture pattern. It is appropriate that each "characteristic" be represented and processed so as to contain all the features inherent in edge representation (perspective, size, brightness, occultation, etc.)

CLOUDS

The CGI system provides for operator selection of cloud condition ranging from overcast to clear skies. The bottom of clouds can be placed at any height above ground level while cloud tops can be at any altitude above the bottoms.

Clouds are treated as objects and are able to be placed where needed and given appropriate motions, with appropriate shape and size functions of time. Solid cloud covers and scud clouds are, therefore, modeled in the data base.

SUN SIMULATION

The sun's glare and horizon glow is modeled by two-dimensional model at infinity. Since shading of all objects is computed at execution time, the location of the sun can be dynamic. It can thus be updated every "frame" along with its effects upon the shading of the world.

When the sun is masked by clouds, it results in a diffuse illumination of the world. This kind of light source, which is not truly directional, is handled by altering the brightness of fall-off function from an angle defining the direction of the light source and the direction of the surface. The fall-off function is a slower fall-off function than normally encountered with a point light source at infinity.

SUMMARY

In recent years, we have come to realize that physiological motion cues are but one part of a total simulation experience. It must be augmented by the "visual" cue which appears to have become accepted as the more important aspect of the two. In the past, we have seen a transition of Visual System techniques from Film Projection to Terrain Model Boards with current enthusiasm for Computer Generated Image Systems. In the competitive struggle for increased realism, the COMPUTROL Computer Generated Image System has come of age due to its ability to dynamically change scene content in real-time. Not only is there freedom of eye movement around a particular CGI model, but also the capability to effect a "complete" change of gaming area in reasonable time. The goal of our research and development efforts has been to incorporate current "chip" technology, resulting in a new computer design capable of high-speed data handling. The objective was to create a full-color raster scan simulation of a three-dimensional real world. We recognize that the product of our research and development efforts should match the following criteria.

- Resolution and fidelity of the final scene should closely equate to that of optical or high-quality film systems.
- Minimal power requirements for economical operation.
- Inherent capability to quickly change entire gaming areas.
- Gaming data size sufficient to permit extended flight simulation without reaching the limit of stored data.
- High-speed computation to permit dynamic movement of objects within the displayed scene, e.g. moving vehicle (land, sea, or airborne).
- System design sophistication to permit miniaturization of the entire system.
- Reasonable purchase price and cost of ownership. Affordable by a majority of customers.

We feel confident that our research efforts have met these seven basic criteria. A 16,000 edge full-color static demonstrator has been developed. Capability to generate high-definition pictures with variable sun angle, smooth shading, and the occultation of hidden surfaces has been proven. Occulting of objects through the visible edge solution guarantees nonbleed through of hidden lines. Another feature of the COMPUTROL,windows look

like windows rather than holes in buildings. The transition to and from clouds is also much more convincing.

System architecture and special algorithms are used to permit the incorporation of texturing with respect to trees, grass, clouds, and water. The key ingredient of the system design is the "atom" philosophy of geometric forms used as building blocks for the total scene model. The basic forms are stretched, squashed, lengthened and/or added to other geometric forms to develop a particular scene. The modeling and use of atoms is performed in the off-line mode where there is the ability to generate and modify scenes as well as to edit and assemble programs. With the exception of flight data or any other vehicle interface which is resident within a simulator "host computer," the visual system is a self-contained digital image generator with bulk storage of specific geographic areas. The current design has the capability of displaying 30,000 edges. The surfaces can be planer or spherical due to the systems' ability to smooth-shade curved surfaces. There is virtually no limit to the number of edges that can be contained within the gaming area data base. The special-purpose CPU used with the image generation system has been especially developed to provide the computational speed necessary within the total system. Risk normally associated with a specially designed computer system has been substantially reduced due to the use of standard MOS chips and straight-forward computer architecture. The resulting CGI technology promises to set the standard for visual simulators for many years to come.

ABOUT THE AUTHORS

DR. RON SWALLOW is a Research Scientist with HumRRO in Alexandria, Virginia and was one of the principle contributors to the development of COMPUTROL Computer Generated Image Display System. He holds a B.S. degree in physics from the University of Illinois, and an M.S. degree in electrical engineering and the Ph.D. from Purdue.

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MR. RUDI R. DRAUDIN is Manager of Systems Marketing at Advanced Technology Systems, Roselle, New Jersey. He is involved in application of navigational systems and visual display attachments to operational and simulated equipment. He holds a B.S. degree in physics from the University of Connecticut.